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A Survey of Soil Disturbance on Groundskidded and Cable-Yarded Clearcuts in the Nelson Forest Region of British Columbia

by

(C) Raymond Keith Krag

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

Department of Forest Science

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "A Survey of Soil Disturbance on Groundskidded and Cable-Yarded Clearcuts in the Nelson Forest Region of British Columbia" submitted by Raymond Keith Krag in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Groundskidding logging systems disturb a larger proportion of the cutover area than cable or aerial logging systems. Researchers have shown soil disturbance is strongly linked to accelerated soil erosion and to poorer regeneration and slower growth of trees. As a result the desirability of using groundskidding systems has been questioned in some regions, including the Nelson Forest Region of southeastern British Columbia.

To investigate this concern, exposed mineral soil was measured on twenty-five groundskidded and six cable-yarded clearcuts in the Nelson Forest Region. Haul roads, landings, skid roads and off-road (yarding) occurrences were included in the surveys. Groundskidding caused significantly more soil disturbance than cable logging. Average mineral soil exposure was 45.4% (range 28.8 to 65.0%) on summer groundskidded blocks; 40.4% (range 13.7 to 52.6%) on winter groundskidded blocks; 29.5% (range 21.5 to 39.9%) on summer cable-yarded blocks; and 22.3% (range 12.3 to 28.4%) on winter cable-yarded blocks.

Skid roads were responsible for most disturbance on groundskidded clearcuts while haul roads were the largest single source on cable-yarded areas. Haul road- and yarding-related disturbance levels were similar for both logging systems. Landing-related disturbance, a minor component of total disturbance for both logging systems, was somewhat greater on groundskidded blocks than on cable-yarded blocks.

Summer groundskidding generated more very deep (19.2%) than deep (16.2%) or light (10.0%) disturbance, while winter groundskidding generated more deep (16.1%) than very deep (13.6%) or light (10.7%) disturbance. Summer cable-yarded sites were characterized by more light (15.1%) than very deep (8.9%) or deep (5.5%) disturbance, whereas winter cable-yarded sites showed an opposite trend: more very deep (14.3%) than light (4.3%) or deep (3.7%) disturbance. The high level of light disturbance on summer cable-yarded sites was associated with a high level of yarding-related disturbance, while on winter-logged sites the high level of very deep disturbance corresponded to a high level of haul road-related disturbance.

Depth of disturbance correlated strongly with source of disturbance. Haul roads and landings generated mostly very

deep disturbance and little light disturbance. Yarding disturbance was usually light.

Season of logging had no significant effect on soil disturbance levels or depth distributions for either logging system. Soil disturbance correlated weakly with slope steepness as well, with only isolated significant effects: skid roads generated more soil disturbance on moderate and steep slopes (steeper than 20%) than on gentle slopes (less than 20%), while landings caused less disturbance on steep slopes (40%+) than on gentle and moderate slopes (up to 40%). Also, skid roads appeared to generate more very deep and less light disturbance as slope steepness increased, but no similar trends were noted among other disturbance sources.

Skid road surfaces on two groundskidded sites were sampled for pH, carbon contents, bulk densities, particle-size distributions and infiltration rates of surface soils, and were compared to adjacent undisturbed surface soils and subsoils. Skid road surfaces resembled subsoils more than surface soils in most respects, being characterized by higher pH, higher bulk density and reduced short-term (fifteen-minute) infiltration rates than surface soils.

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1. INTRODUCTION

Soil disturbance, the exposure of mineral soil by mechanical action, is a normal consequence, and sometimes a desirable objective, of timber harvesting. Scarification, for example, is routinely prescribed to prepare cutover sites for natural regeneration or planting. It is also recognized, however, that soil disturbance can have detrimental impacts on some forest sites. Soil erosion, sedimentation, and losses in site productivity are probably the most frequently-cited impacts. Researchers generally agree that the potential for soil erosion to occur, if not the actual rate of erosion, increases as the extent of soil disturbance increases. A substantial body of literature also demonstrates that tree growth on some disturbed sites may be impaired by compaction or other alterations to the physical and chemical properties of the soil. As a result of these concerns, many scientists and foresters have promoted the reduction of soil disturbance as an important goal of forest management, arguing that the potential for harmful impacts will be reduced accordingly.

Although soil disturbance may suggest certain impacts, its value as an index or predictor of the type, magnitude and

severity of these impacts is not clear. It is an appealing index because it can be relatively easily and objectively measured, whereas environmental impacts are difficult to quantify. However, the processes that link soil disturbance to losses in site quality are complex and cannot be adequately described by soil exposure alone. Soil erosion varies not only with mineral soil exposure, but also soil, topographic and climatic factors. Changes in site productivity are also the result of complex interactions between physical and chemical properties of the soil and the hydrologic and climatic characteristics of the site.

Despite these limitations, soil disturbance has been widely used by many researchers as a criterion to assess the relative environmental impacts of aerial, cable and groundskidding logging systems. With few exceptions comparisons between logging systems have been made on the basis of the total area disturbed without regard for differences in cause or severity of disturbance. Using this index of total soil disturbance, most of these studies have suggested that groundskidding logging methods cause greater impacts than aerial or cable methods. These findings have helped to entrench the opinion that aerial and cable-yarding systems are inherently superior to groundskidding systems in terms

of their environmental effects. They have also been cited as evidence in support of proposals to restrict or abolish logging by groundskidding methods in some regions.

Comparisons that are based primarily or entirely on extent of soil disturbance, and particularly on total soil disturbance, usually leave many important related questions unresolved. First, how meaningful are the results? Most comparisons are based on only a few logged areas and statistical analyses are lacking. Also, physical descriptions and details of the logging histories of the study sites vary in quality. This makes it difficult to determine whether or not the sampled areas are truly representative of average logging conditions and practices for the region.

Secondly, is the soil disturbance caused by cable or aerial logging methods inherently different (aside from areal extent) from that caused by groundskidding? In terms of the processes that contribute to soil disturbance, felling and road construction are common to all logging methods; properties of soil disturbance associated with these sources are not likely to vary much between logging systems. However, groundskidding systems differ from cable and aerial systems in the yarding process, using tractors or rubber-tired

skidders to transport logs from the stump to the landing. On sloping ground these vehicles operate on skid trails, which constitute an additional source of disturbance not associated with most cable or aerial systems. There is strong evidence linking skid road-related soil disturbance to detrimental impacts such as soil erosion, compaction, and reduced tree seedling vigour and survival. While it is clear that skid roads are therefore a source of additional (and potentially detrimental) disturbance, the significance of this increase is less obvious. It is necessary to determine the proportions of total soil disturbance attributable to haul roads, landings, skid roads and yarding activities in order to put the role of skid road-related disturbance, and therefore of groundskidding systems in general, into proper perspective.

Finally, how readily can the results from one area be extrapolated to other regions? Soil disturbance information is available for a variety of climatic, topographic and edaphic settings, but its usefulness is limited by differences in sampling methods, measurement criteria and definitions among the studies.

This thesis attempted to address these questions in an investigation of the occurrence, distribution and depth of soil disturbance on cutover areas in the Nelson Forest Region of southeastern British Columbia.[1] Greater public awareness of environmental issues coupled with the forest industry's increasing dependence on timber from high-elevation steep slopes generated strong controversy over the traditional logging practices of the regional industry. The controversy emphasized the lack of and need for reliable quantitative information about the environmental effects of logging on steep, high-elevation sites.

In 1973 the British Columbia Forest Service issued logging guidelines for the Nelson District (British Columbia Forest Service, 1973, 1974) (Appendix I, page 180). The intent of

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[1]The British Columbia Forest Service was reorganized under the Ministry of Forests Act (1980) in response to the recommendations of the Royal Commission on Timber Rights and Forest Policy in British Columbia (Pearse, 1976, Volumes 1 and 2). The six administrative units formerly referred to as Forest Districts are now called Forest Regions (boundaries of two central interior Districts were revised to create a seventh Forest Region). Administrative boundaries of the Nelson Forest Region were not changed but management units within the Region, formerly called Public Sustained Yield Units (PSYU's), have been grouped into fewer, larger Timber Supply Areas (TSA's). Other tenure agreements, conferring cutting rights and management responsibilities, remain in force with minor amendments.

the guidelines was to encourage operators in the region to use cable logging systems on steep, potentially sensitive sites. Tractor logging on slopes between 50 and 70% was limited to winter operations on deep snow-packs, and was prohibited entirely on slopes steeper than 70 percent.

Most of the Region's remaining mature timber stands occupied steep slopes at high elevations. Hedin (1978) estimated that 32% of the mature timber remaining in the Nelson Forest Region was on slopes of 34 to 50%, and 34% was on slopes steeper than 50 percent. Average elevation of mature stands was 5,000 feet (1 520 metres). There were also pressures to reduce the allowable annual cut (AAC) to account for land withdrawals for wilderness and park areas and to exclude timber harvesting on sites that were economically inaccessible or environmentally too sensitive to log.[2] As a result of these pressures the mature timber on steep high-

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[2]In 1976 the B.C. Forest Service began a program to identify, map and cruise environmentally-sensitive sites, termed Environmental Protection Areas (EPA's) (British Columbia Forest Service, 1976). Logging within an EPA was to be restricted depending upon the nature and severity of the site problems. The program was intended to form the basis for recalculating the allowable annual cut for each PSYU. The Royal Commission on Timber Rights and Forest Policy in British Columbia (Pearse, 1976) recommended continuing the EPA program.

elevation sites was becoming an increasingly important source of timber.

At the time the guidelines were introduced over 95% of the timber harvested annually in the Region was logged with tractors (Wellburn, 1975). He stated the industry's problem (page 52):

> "Tractor logging is the most economic and safest logging system for many areas of the Nelson Forest District and being adaptable, it provides the longest operating season. Erosion and soil damage could be reduced by planning and supervision. Information on the extent of damage from tractors is lacking and as a result many people blame tractors for damage to areas which they find aesthetically unpleasant."

The Steep Slopes Committee for the Nelson Forest District was formed in 1974 to resolve issues concerning steep-slope logging practices. Members represented the British Columbia Forest Service, Interior Lumber Manufacturers' Association, Forest Engineering Research Institute of Canada, British Columbia Environment and Land-Use Committee Secretariat, and Canadian Forestry Service. The Committee requested the Pacific Forest Research Centre and Forest Engineering Research Institute of Canada to initiate studies of logging impacts on steep slopes. This study formed part of FERIC's contributions.

The current study had two goals. The first was to survey groundskidded and cable-yarded cutovers to document and analyze levels, composition and severity of soil disturbance over a range of harvesting methods and site conditions. The specific objectives were to:

1) determine whether groundskidding systems generated more soil disturbance than cable-yarding systems;

2) determine why differences, if any, occurred;

3) using depth of disturbance as an index, compare the severity of soil disturbance between the two logging systems; and

4) examine the effects of slope steepness and season of logging on soil disturbance levels.

The second goal of the study was to describe the effects of skid road construction and use on properties and characteristics of forest soils. The impacts of skid roads on various soil properties, most notably on bulk density and fertility, and their consequent effects on infiltration rates, surface erosion and tree growth, have been discussed by several researchers. Most of this information applies to areas of gentle topography, however; comparable information for glaciated mountainous terrain such as is typical of the Nelson Forest Region is scarce. Therefore the second phase of this study consisted of a survey of physical and chemical properties of soils on skid road surfaces and on adjacent

undisturbed sites. It also included measurement of rill erosion on skid roads and its correlation with skid road gradient and length. The objectives of this survey were to:

1) correlate selected physical and chemical characteristics of the soil with skid road-related disturbance; and

2) provide an indication of the magnitude and direction of alterations to soil properties that result from skid road construction and use.

2. LITERATURE REVIEW: TIMBER HARVESTING AND SOIL DISTURBANCE

2.1. Timber Harvesting and Soil Disturbance

Researchers have measured and compared soil disturbance for a variety of logging systems. While various indices of disturbance have been proposed, exposed mineral soil is the most universally accepted index. A common theme has been to contrast groundskidding logging systems (rubber-tired skidders or tractors) with one or more cable or aerial systems. Many researchers have further described soil disturbance by its source (usually haul roads, landings, skid roads and yarding) and/or by its severity (usually some depth criteria). Some researchers have also studied the effects of season of logging and slope steepness on the quantity and severity of soil disturbance.

Most of the early soil disturbance research was done in the western United States. Fowells and Schubert (1951) reported mineral soil exposure averaged 22% on tractor- and donkey-logged cutovers in California pine stands, with revegetation decreasing the percentage of bare ground to 8% by 12 years and to 2% by 24 years after logging. In a similar study,

Garrison and Rummell (1951) found tractors exposed mineral soil on 20.9%, cable (jammer) systems on 15.2%, and horses on 11.8% of the area logged by each system in ponderosa pine rangelands of central Washington and Idaho.

Haupt (1960) concluded the number of stems removed per acre was the key factor affecting mineral soil exposure in a comparison of stem versus group selection harvesting methods in Idaho ponderosa pine stands. Soil disturbance averaged 8.1% overall for all harvesting and logging (groundskidding) methods combined, but increased with increasing intensity of cut, initial stand volume, and size of tractor.

Wooldridge (1960) compared tractor and skyline crane logging systems in north-central Washington and observed 29.4% of the tractor-logged site and 11.1% of the skyline crane-logged site were disturbed. Dyrness (1965) reported similar results for a study in southwestern Oregon noting that 28% of a tractor-logged clearcut was disturbed by skid roads, while disturbance on three highlead-logged sites averaged 14.8 percent.

A more recent study of a salvage logging operation in north-central Washington contrasts strongly with the similar

findings of these earlier studies. Klock (1975) reported tractors and "traditional" cable-logging methods (jammer and highlead) disturbed 73.8 and 76.5%, respectively, of their salvage-logged areas. "Advanced" logging systems disturbed much smaller proportions of their logging areas: Tractor logging over snow caused 34.0% disturbance, skyline logging 25.2%, and helicopter logging only 12.0 percent. (Klock does not define the terms "traditional" and "advanced" but in the context of his study it is presumed that "advanced" systems are perceived to have less detrimental impacts on forest sites than "traditional" systems.)

Zasada and Tappeiner (1969) reported summer logging with rubber-tired skidders disturbed 67 to 83% of four northern Minnesota aspen sites, with 7 to 11% of the areas heavily disturbed. Another study in northern Minnesota compared full-tree and tree-length harvesting systems, also using rubber-tired skidders, where full-tree systems caused 47% disturbance in winter and 78% in summer, compared to 47% in winter and 72% in summer for tree-length systems (Mace, Williams and Tappeiner, 1971).

A survey of nine rubber-tired skidder- or tractor-logged areas in the Coastal Plains region of South Carolina and

Virginia revealed primary skid trails disturbed an average of 12.4% (range 3.2 to 22.8%) and secondary skid trails an average of 19.9% (range 8.8 to 42.3%) of the total logged area (Hatchell, Ralston and Foil, 1970). Log decks (landings) occupied an average of 1.5% (range 0.3 to 4.6%) of the logged sites.

In recent years soil disturbance surveys were undertaken in British Columbia. Bockheim, Ballard and Willington (1975) reported mineral soil was exposed on 68 and 71% of two tractor-logged blocks in southwestern British Columbia, while soil disturbance averaged 29% on eleven highlead-logged clearcuts in the same region. In a survey of clearcuts in southeastern British Columbia, Smith and Wass (1976) recorded average mineral soil exposures of 46% (summer) and 29% (winter) for groundskidding logging methods; 17% (summer and winter) for highlead-yarding systems; and 29% (summer) and 22% (winter) for grapple-yarding systems. Hammond (1978) surveyed eight cutblocks logged with small tractors in the same region, reporting soil disturbance averaged 28% on summer-logged blocks and 39% on winter-logged blocks. Schwab and Watt (1981) found in the central interior, tractors disturbed between 35.1% and 59.8% (average 46.1%) of eleven summer- and winter-logged blocks, while running skyline

systems disturbed only 8.8% to 17.4% (average 11.6%) of four summer- and winter-logged clearcuts.

The primary sources of soil disturbance on most logged areas are haul roads, landings (log decks) and skid roads. Silen and Gratkowski (1953) provided an indirect estimate of disturbance attributable to haul roads and landings in their study to determine how much forest land was required for efficient log transport. A total of 12.4% of the area of 12 clearcut units in the H.J. Andrews Forest in the Oregon Cascades (8.8% in haul roads and 3.6% in landings) was occupied by the road network. However, the authors estimated that for the entire Forest, disturbance levels would be lower, 2.9% in roads and 1.2% in landings, for a total of 4.1% overall. Mitchell and Trimble (1959) found unplanned skid roads disturbed a larger area than carefully planned skid roads (5.6% versus 4.5% of the logged sites) on the Fernow Experimental Forest in West Virginia. By comparison a horse-logging operation on the Fernow Forest resulted in 12% of the area being severely disturbed by skid trails. Haul roads disturbed 0.9% of the skidder-logged area and 0.5% of the horse-logged area. Kochenderfer (1977) reported 10.3% of skidder-logged areas and 7.8% of jammer-logged areas in the central Appalachians was disturbed by skid

roads, haul roads and landings. On the skidder-logged areas 84% of the soil disturbance was due to skid roads and 16% to haul roads, while only 4% of disturbance was due to skid roads and 96% to haul roads on the jammer-logged areas. In another study of nine cutovers in the Douglas-fir region of southwestern Washington, skid roads alone disturbed an average of 26.1%, with a range of 17.3 to 34.5%, of the logged area (Steinbrenner and Gessel, 1955).

Road-related disturbance on eight tractor-logged units in southeastern British Columbia ranged from 21.5 to 46.4% and averaged 34.3% (Hammond, 1978). Another study reported deep soil disturbance (soil gouges and deposits deeper than 0.25 metres) caused by haul road, landing and skid trail construction amounted to 13.8% and 18.4% of two tractor-logged clearcuts in the East Kootenays, but only ranged from 4.8 to 6.0% on three highlead-logged areas in the southwestern portion of the province (Utzig and Herring, 1975).

Smith and Wass (1976) found haul roads, skid roads and landings collectively disturbed 39.8% of the area of clearcuts that had been summer tractor-logged. Clearcuts tractor-logged during the winter, however, had an average disturbance of 21.3 percent. Road-related disturbance on cable-

logged clearcuts averaged 9.0 and 16.4% (summer and winter) for highlead systems, 27.1 and 21.8% (summer and winter) for grapple yarding systems, and 7.7% for summer jammer yarding.

Not all researchers have included haul roads and landings in their estimates of soil disturbance for cable-yarded clear-cuts, making direct comparisons of total soil disturbance levels between studies difficult. Even when the presence or absence of haul roads and landings is taken into account, however, other inconsistencies in the disturbance estimates become evident. For example, studies of highlead-logged sites that have included haul roads and landings yield soil disturbance estimates ranging from 9% to slightly more than 24% (Garrison and Rummell, 1951; Ruth, 1967; Smith and Wass, 1976). By comparison, studies that have not included haul roads and landings show a far wider range in disturbance estimates, from one percent to almost 77 percent (Bockheim et al., 1975; Dyrness, 1965; Klock, 1975; Watt, 1975). It would appear that most of these inconsistencies reflect specific site conditions. The factors contributing to Klock's (1975) observation of 76.5% disturbance on a highlead-logged setting are not clear, but it should be noted that the area was logged after a wildfire. Watt (1975) also reported a value of 67% mineral soil exposure on one highlead-

logged area that had been burned before logging. The very low highlead disturbance estimates also seem to be due to special conditions. Deep litter layers (25-48 cm), heavy slash accumulations and good deflection are probably responsible for the very low soil disturbance (1%) reported by Watt (1975), while Bockheim et al. (1975) credit yarding over snow with causing only 5% soil disturbance on a clearcut in southwestern British Columbia.

Estimates of soil disturbance (excluding haul roads and landings) are generally lower for skyline than for highlead systems and range from 5.4% to 12.1% (Dyrness, 1967; Ruth, 1967; Schwab and Watt, 1981; Smith and Wass, 1976; Wooldridge, 1960). However, Klock (1975) reported a much higher figure (25.2%), and Cromack, Swanson and Grier (1979) also stated that a skyline-logged unit in southwestern Oregon experienced a much higher degree of soil disturbance than other skyline studies but did not provide an estimate of mineral soil disturbance for comparison.

Apparently only Smith and Wass (1976) have surveyed grapple-yarded clearcuts, reporting road-related disturbance levels of 27.1 and 21.8% for summer- and winter-logged sites, respectively.

Soil disturbance data are available for two aerial logging methods, balloon logging and helicopter logging. Mineral soil was exposed on six percent of surveyed balloon-yarded clearcuts (Dyrness, 1972). Soil exposure on helicopter-logged clearcuts is also low: 5% on a clearcut in south-western British Columbia (Bockheim et al., 1975), 5% on a clearcut in the Idaho Batholith (Clayton, 1981) and 12% on a clearcut in north-central Washington (Klock, 1975).

Only a few studies have searched for or reported slope and season-of-logging effects on soil disturbance levels. Garrison and Rummell (1951) noted that deep soil disturbance (soil displacement deeper than one inch, by the authors' criteria) caused by tractors averaged 2.8 times greater on slopes greater than 40% compared to slopes less than 40 percent. Bockheim et al. (1975), by comparison, measured mineral soil exposures of 68 and 71% on two tractor-logged clearcuts having very different average slopes (25% and 60%, respectively) but concluded that "on highlead settings, slope angle appears to be a major factor influencing the degree of mineral soil disturbance" (page 289).

Data presented by Hammond (1978) for eight tractor-logged sites in the East Kootenays show no apparent correlation

between slope steepness and degree of disturbance. Smith and Wass (1976) found, over a slope range of 29 to 81%, slope steepness did not influence soil disturbance caused by summer-built skid roads. On winter-logged areas, however, twice as much skid road disturbance occurred on slopes greater than 60% compared to slopes of less than 60 percent. Schwab and Watt (1981) observed soil disturbance on eleven tractor-logged clearcuts in the Quesnel Highlands increased consistently from 41.3% on 0-30% slopes, to 50.2% on slopes greater than 60 percent. Skid roads disturbed 31.6% of the clearcut area on 0-30% slopes, 38.8% on 31-60% slopes, and 47.4% on slopes greater than 60 percent.

Apparent seasonal effects have also been noted by some researchers. Bockheim et al. (1975) reported highlead yarding on a 65% slope over a spring snowpack resulted in only 5% mineral soil disturbance on one clearcut, compared with an average of 31% for twelve areas that were logged in snow-free periods. In north-central Washington tractor logging over snow caused 34% soil disturbance while tractor logging over bare ground (presumably in summer or fall) generated 73.8% soil disturbance (Klock, 1975). A study in Minnesota reported groundskidding in winter reduced total soil disturbance by about 30% compared to summer logging

(Mace, Williams and Tappeiner, 1971). In a more comprehensive analysis of seasonal differences, Smith and Wass (1976) found (1) on groundskidded sites, soil disturbance averaged 41.9% in summer and 24.5% in winter; (2) on highlead-logged sites, soil disturbance averaged 9.0% in summer and 16.4% in winter; and (3) on grapple-yarded sites, soil disturbance averaged 27.1% in summer and 21.8% in winter.

2.2. Timber Harvesting and Soil Compaction

Timber harvesting activities usually cause some soil compaction in addition to exposing mineral soils. The extent and severity of compaction varies with the logging system, intensity of traffic, soil moisture condition and soil texture (Dyrness, 1965, 1967, 1972; Terry and Campbell, 1981). Soils may remain compacted for several years after logging, with adverse effects on tree regeneration, survival and growth (Froehlich, 1979).

Substantial proportions of cable-logged sites may be compacted by yarding. Dyrness (1965, 1967, 1972) found soils were compacted to some degree on 27% of a tractor-logged unit, 9% of a highlead-logged unit, and 2% of a balloon-

logged unit. Cromack et al. (1979) reported 10% slight compaction and 20% deep compaction occurred on a skyline-yarded clearcut in western Oregon, attributing the high degree of compaction to poor deflection. Harr and McCorison (1979) also reported extensive soil compaction (19.8%) on a skyline-logged unit in western Oregon.

The areal extent of compacted soils on groundskidded sites is closely correlated with the area in skid trails, haul roads and landings. Garrison and Rummell (1951) observed skid trails on their study sites were heavily compacted. Froehlich, Aulerich and Curtis (1981), citing studies by Foil and Ralston (1967) and Froehlich (1976)[1], state "The soil in the skid trails is almost always compacted" (page 2). Ballard (1972) summarizes studies by Steinbrenner (1955) in southwestern Washington showing an 80% reduction in soil permeability and 50% reduction in macro-pore space due to tractor traffic. Skid roads on nine tractor-logged blocks in southwestern Washington were found to have bulk densities increased by 35% and permeability rates reduced by

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[1]Original reference not available:
Froehlich, H.A. 1976. The influence of different thinning systems on damage to soil and trees. In: Proceedings XVI IUFRO World Congress, Division IV, Norway. p. 333-344.

92% when compared to adjacent undisturbed soils (Steinbrenner and Gessel, 1955). Seedlings on skid road surfaces were fewer in number and inferior in quality to seedlings on the adjacent cutover land. Hassan (1978) reported skidder logging on a wet Coastal Plain soil in North Carolina caused bulk densities in the 0-15 cm zone beneath the root mat layer to increase by as much as 50 percent. Mace (1970) found tree-length and full-tree logging in summer with rubber-tired skidders caused bulk densities to increase 5 and 11%, respectively, on sandy soils in northern Minnesota.

Dyrness (1965) recorded soil bulk densities of 0.60 and 0.50 g/cm^3 on undisturbed and slightly disturbed sites; 0.77 g/cm^3 for deeply disturbed sites; and 0.98 g/cm^3 for compacted sites (skid trails) on a tractor-logged area in southwestern Oregon. Youngberg (1959) measured bulk densities of 1.52 to 1.58 g/cm^3 in the top 6 inches and 1.59 to 1.73 g/cm^3 at 6- to 12-inch depths on tractor-road surfaces, also in Oregon. By comparison, bulk densities in the road berm ranged from 0.88 to 1.05 g/cm^3. The author considered that part of the increase may have been due to the naturally higher bulk densities of subsoil layers.

Mace, Williams and Tappeiner (1971), comparing the effect of winter logging with rubber-tired skidders by full-tree and tree-length logging systems, found soil bulk densities in the surface two inches of soil were 0.4 to 0.5 g/cm^3 greater in heavily-disturbed than in lightly-disturbed areas for both systems.

Bulk density tends to increase with increasing traffic use. A survey of nine Atlantic Coastal Plain sites logged with either rubber-tired skidders or crawler tractors showed soil bulk density increased and infiltration rates and air space decreased with increases in logging traffic intensity (Hatchell, Ralston and Foil, 1970). Most of the increase in bulk density occurred in the first two passes of the logging machinery, and for most locations 90% of final bulk density was achieved after four passes. Campbell, Willis and May (1973) reported the bulk density of a Georgia Piedmont soil increased from 1.34 to 1.41 g/cm^3 after one pass, to 1.44 g/cm^3 after ten passes.

Soils tend to be compacted more rapidly and more severely when wet than dry. Medium- to fine-textured soils tend to suffer the most severe compaction, particularly when soil moisture contents are at or slightly below the level held

at -0.33 kPa of tension (Terry and Campbell, 1981). Bulk densities of wet, silty loam soils increased by 13% and macroscopic pore space decreased by 49% in the 0- to 2-inch layer as the result of high traffic intensities (Moehring and Rawls, 1970). Hatchell, Ralston and Foil (1970) also concluded logging on medium- to fine-textured soils during wet weather resulted in severe soil compaction and puddling.

High soil bulk densities may persist for several years after logging (Adams and Froehlich, 1981; Froehlich, 1979). Froehlich (1979) reported 16 years after logging, soil bulk densities at 9- and 12-inch depths were 18% and 9% greater, respectively, on skid trails than in adjacent undisturbed soils of an Oregon ponderosa pine stand. Dickerson (1976) reported tree-length logging with rubber-tired skidders on a northern Mississippi site caused soil bulk densities in wheel rut areas and log-skidded areas to increase by 20% and 10%, respectively, when compared to bulk densities of adjacent undisturbed soils. Recovery was gradual; five years after logging, bulk densities of skid road and log-skidded soils were still 11% and 4% higher, respectively, than those of undisturbed soils.

In a study in northern Minnesota, sandy soils compacted during tree-length logging with rubber-tired skidders showed a significant decrease after the first winter, whereas soils compacted during full-tree logging did not recover significantly (Mace, 1971). The decrease in bulk density under the tree-length system was attributed to increased soil freezing, reduced vegetative growth due to heavier concentrations of slash, and to a smaller degree of initial compaction (5% compared to 11% under the full-tree system).

Several researchers have reported reductions in tree growth rates that reflect, to some degree, the effects of soil compaction from logging activities (Froehlich, 1979; Hatchell et al., 1970; Moehring and Rawls, 1970; Smith and Wass, 1979, 1980; Steinbrenner and Gessel, 1955; Youngberg, 1959).

2.3. Timber Harvesting and Soil Erosion

Even if the physical processes governing erosion were incompletely understood in light of today's knowledge, foresters very early recognized a strong link between timber harvesting and soil erosion. A good example is

provided by McCallie (1922), who ascribed severe gullying in northern Georgia to removal of timber on gully slopes. Numerous other studies have made similar observations.

Soil erosion rates under forest cover are generally lower than under other types of ground cover (Eschner and Peroutky, 1981), but increase above natural levels when a watershed is disturbed by activities such as timber harvesting (Anderson et al., 1976; Fredriksen, 1972; Gibbons and Salo, 1973; Megahan, 1972, 1975, 1977). The link connecting timber harvesting, soil erosion and soil disturbance is succinctly explained by Patric (1976). In a review of pertinent literature, the author cites supporting evidence to show that undisturbed forest soils are able to absorb virtually all precipitation, thereby almost eliminating overland flow, the principal mechanism for soil erosion and transport. It follows that soil erosion from logged areas can only come from disturbed sites such as haul roads and skid trails.

Erosion in excess of natural levels - "accelerated erosion" - may reflect increases in three kinds of erosion -- channel scour, mass wasting, and surface erosion. Accelerated erosion from logged sites is usually considered to be due to

increases in mass wasting and surface erosion. Swanston (1971) considered mass wasting to be the dominant form of erosion in western North America. Relationships between timber harvesting activities and mass wasting processes have been extensively researched and documented in this region. However, numerous researchers have documented through water quality studies, erosion-plot studies and general observation that surface erosion processes can also cause serious soil losses from logged sites (Bethlahmy, 1960, 1967; Brown and Krygier, 1971; DeByle and Packer, 1972; Dickerson, 1975; Fredriksen, 1970; Haupt, 1959a; Megahan, 1975, 1978; Megahan and Kidd, 1972a; Packer, 1967; Packer and Haupt, 1965; Reinhart, Eschner and Trimble, 1963; Weitzman and Trimble, 1952).

The basic principles and processes of surface soil erosion are well established. This research has lead to the development of a variety of surface erosion models of varying degrees of complexity. However, most of the early studies (and many of the models) have an agricultural perspective. Two assumptions implicit in much of this work limit extrapolation to forest management practices:

(i) the research usually applies to very gentle slopes;

(ii) soil cover is usually assumed to be absent.

Erosion research on forest and rangeland soils tends to give more emphasis to the effects of slope and ground cover on erosion rates. Sediment routing is another important aspect of wildland erosion processes. As Cromack et al. (1979) states:

> "Soil/sediment movement through ecosystems is viewed as a series of storage sites linked by transfer processes .... To assess management impacts on soil loss and sedimentation one must understand this soil/sediment routing system and identify major processes and storage sites on land and in streams" (page 450).

Surface erosion is negligible in undisturbed forests because litter and duff layers contribute to infiltration rates far in excess of natural rainfall intensities, thereby minimizing the occurrence of overland flow (Megahan, 1976; Patric, 1976). Lowdermilk (1930), in an investigation into the influence of litter cover on the hydrologic characteristics of a soil, compared amounts of surface runoff and soil erosion for litter-covered and bare (burned) California forest soils. Runoff was 3.7 times greater and soil erosion 18.1 times greater on the burned as compared to the unburned plots. The author concluded,

> "(1) Forest litter in these experiments greatly reduced surficial runoff, particularly in the finer textured soils; and this influence continued long after the litter was completely saturated," and "(2) Destruction of the litter and the consequent exposure of the soil greatly increased the amount of the eroded material and reduced the absorption rate of the soil" (page 490).

Studies on the effects of timber harvesting on soil erosion rates usually identify two sources of sediment - roads and logging. Road-building (both haul and skid roads) is generally regarded to be the most important of the two (Anderson et al., 1976; Fredriksen, 1970, 1972; Haupt and Kidd, 1965; Megahan, 1976, 1977; Packer and Christensen, 1964; Patric, 1976; Patric and Kidd, 1981; Rothwell, 1971).

A study in west-central Alberta reported a logging road contributed an average of 816 pounds of sediment per day at a stream crossing during a week-long, 2½-inch rainfall, twice as much as nearby seismic lines (Canadian Forestry Service, 1974). Sediment discharge following construction of a logging road along the south fork of Caspar Creek in northern California was more than four times preconstruction levels during the first winter and slightly above preconstruction levels for the subsequent three years (Krammes and Burns, 1973).

Hoover (1945) identified skid roads as a major source of soil erosion on logged sites in western North Carolina and further discovered that most of the soil loss occurred during logging. Trimble and Weitzman (1953) found soil erosion from skid roads in a West Virginia study increased

as steepness, length, and use of skid roads increased, and also concluded that erosion was much greater during than after skidding. Dickerson (1975) reported that an average of 14.79 kg of soil was eroded annually from skid trails of various lengths (7 to 55 metres) and grades (9 to 35%) in northern Mississippi, compared to an average of only 0.18 kg of sediment per year from adjacent undisturbed plots. First-year erosion rates of 0.37 inches from skid trails 50 feet long and having 5% grades and 1.16 inches from skid trails 250 feet long and having 50% grades were measured on the Fernow Experimental Forest in West Virginia (U.S. Forest Service, 1953). By comparison, Hetherington (1976) attributed slight increases in suspended sediment levels following partial logging of a small watershed in the Okanagan Basin of British Columbia to an effective buffer strip, winter logging on snow, and gentle (25%) slopes.

Several other researchers have observed but not measured significant erosion occurring on mineral soil exposed by road-building (Garrison and Rummell, 1951; Smith and Wass, 1976; Hartsog and Gonsior, 1973; Haupt, Rickard and Finn, 1963).

Hornbeck and Reinhart (1964) compared the effects of four timber harvesting practices (clearcutting, diameter-limit cutting, extensive selection cutting and intensive selection cutting) on water quality on four gauged streams in the Fernow Experimental Forest, West Virginia. The drainages were all tractor-logged; no haul roads or landings were built within the experimental watersheds. Skid road quality also varied among the harvesting treatments: unplanned and uncontrolled in the commercial clearcut; water bars only installed on skid roads used for the diameter-limit cut; preplanned with skid roads away from stream channels and with maximum grades of 20% for the extensive selection cut; and preplanned with maximum grades of 10% for the intensive selection cut. Water turbidity readings taken during logging operations demonstrated the importance of planning and maintaining skid road networks as a means of maintaining water quality. Maximum turbidities of 56,000 and 5,200 ppm were recorded for the commercial clearcutting (no controls on roads) and diameter-limit cutting methods (use of water bars only), respectively. By comparison, turbidity readings for the extensive and intensive selection cuts, both having carefully planned and constructed skid road networks, were 210 and 25 ppm, respectively. Infiltration rates on skid road surfaces averaged 3 inches per hour whereas those of

the adjacent undisturbed forest floor were 50 or more inches per hour. Rate of soil loss decreased rapidly to negligible levels in the second year after logging operations were completed for the commercial clearcut and diameter-limit cuts. The authors attributed the rapid decrease in apparent erosion to rapid revegetation and the development of erosion pavements in the stony soils of the skid road surfaces.

As part of the same study, Reinhart (1964) found overland flow was negligible prior to cutting. After clearcutting overland flow was observed only on skid roads. Infiltration rates off the skid roads were affected very little by logging, but were lowered considerably on bulldozed skid road surfaces, particularly the track areas. The author also felt the skid roads intercepted substantial subsurface seepage flow and converted it into overland flow, accentuating the effect of inadequate infiltration rates and increasing the quantity of overland flow.

Felling and yarding also increase erosion rates but the ranges of increases, up to about five times natural levels, are much less than those reported for roads (Brown and Krygier, 1971; Fredriksen, 1970; Megahan and Kidd, 1972b; Rice et al., 1979). Anderson (1971) predicted future log-

ging and road development in western Oregon would increase sediment production by a factor of four, of which 80% would be due to roads and 20% to logging. In a study in the Idaho Batholith, Megahan and Kidd (1972a, 1972b) reported logging alone caused erosion to increase 1.6 times natural levels, while logging plus road-building caused surface erosion rates to increase by 220 times. Another study in central Idaho reported logging significantly increased soil erosion rates on southwest aspects but not on northeast aspects, probably due to lower levels of surface cover on southwest exposures (Bethlahmy, 1967).

Sediment transport away from the erosion site is governed by several factors which, to varying degrees, influence the amount of sediment that reaches the stream channel. In a statistical analysis of several northern California streams, Anderson (1974, 1975) reported streamside roads caused sediment increases of 690 percent. Hetherington (1976) observed fine sand-sized sediment was filtered out of runoff by buffer strips along the streams in a study in the Okanagan basin. Trimble and Sartz (1957) found length of sediment discharge from culvert outlets on the Hubbard Brook Experimental Forest, New Hampshire, was correlated with culvert spacing and age, road surface condition, road steep-

ness, and topography below the culvert outlet. Haupt (1959b) found good correlations between sediment movement from logging roads and the presence and number of slope obstructions (logs and slash), distance between cross ditches, road gradients, and the slope length of road embankments.

Many studies report surface erosion rates decrease from very high levels initially, to usually a few times above predisturbance levels within a few years. Megahan and Kidd (1972b) reported 84% of the total sediment measured during a six-year study in central Idaho was produced during the first year following logging and road construction, and rose to 93% by the end of two years. Dickerson (1975) observed a similar trend on skid trails in Mississippi, while Hoover (1945) and Weitzman and Trimble (1952) noted soil losses from skid trails were highest during logging operations and decreased thereafter. Erosion studies on logged and burned sites in western Montana also showed surface erosion rates, very high during the first year, had decreased to negligible levels after four years (DeByle and Packer, 1972; Packer and Williams, 1976).

Megahan (1974a), modelling surface erosion rates using data from four erosion studies, proposed the observed time trend

could be described by a negative exponential function that incorporated the geologic erosion rate, an estimate of the amount of soil available to erosion processes, and an exponent that varied with site conditions. Leaf (1974) reported the model also suited data from a central Colorado study. Possible explanations for the sharply-declining trend are revegetation of disturbed surfaces (Dickerson, 1975) and "surface armouring" (Megahan, 1974a).

2.4. Summary of Literature Review

The literature review of timber harvesting and soil disturbance, soil compaction and soil erosion demonstrates the following points:

1) In general, groundskidding logging methods generate more soil disturbance than cable yarding systems, which in turn generate more disturbance than aerial logging methods.

2) Haul roads and landings, common to all logging systems, are probably the primary sources of exposed mineral soil on cable-logged sites. Skid roads are an additional and probably major source on groundskidded sites. Yarding disturbance is also common to all systems, but is generally a minor component of total disturbance.

3) Effects of season of logging and slope steepness on disturbance levels are poorly defined for groundskidding and cable logging methods.

4) Areas of compacted soils are closely associated with areas disturbed by haul roads, landings and skid roads. Soils under yarding roads may also be compacted but generally to a lesser degree than road surfaces.

5) The degree of soil compaction varies with soil texture, soil moisture condition, and intensity of traffic use. As a rule, soil bulk density increases as soil texture becomes finer, soil moisture content and traffic use increases. Most of the compaction occurs during the first few passes of logging traffic.

6) Compacted soils exhibit reduced pore space and infiltration rates, and poorer survival and growth of trees. The effects of compaction may persist for several years.

7) Surface soil erosion occurs at near-minimum levels under forest cover because litter and duff layers have infiltration rates far in excess of natural rainfall intensities. As a result overland flow, the primary cause of surface erosion, is minimized.

8) Timber harvesting increases soil erosion and sediment production rates. Overland flow of water on disturbed surfaces is responsible for these increases.

9) Both road-building and logging cause increased sediment production. Roads are generally the major source of eroded soil. Erosion on skid roads can also be severe as long, steep gradients can concentrate surface runoff and increase its erosive power.

10) Erosion rates are highest during and immediately following logging, and decrease rapidly thereafter. Reasons cited for the rapid decrease in erosion rates are surface armouring and revegetation of disturbed surfaces.

3. STUDY METHODS

3.1. Background

This study took place in the Nelson Forest Region of south-eastern British Columbia (Figure 1).

The Nelson Forest Region is a mountainous area and lies within the Cassiar-Columbia Mountains and Eastern System physiographic regions of British Columbia (Farley, 1979). From west to east the Nelson Forest Region encompasses parts of four major mountain ranges: the Monashee, Selkirk and Purcell Mountains (all within the Cassiar-Columbia region), and the Rocky Mountains (Holland, 1976; Jackson, 1976). The Monashees, Selkirks and Purcells consist of sedimentary rocks of Proterozoic age with areas of younger metamorphic and igneous rocks, while the younger Rocky Mountains are primarily sedimentary rocks of Paleozoic age (Holland, 1976).

Relief increases from south to north. Valley bottoms lie at 500 to 600 metres and summits at 2 100 to 2 300 metres in the south. In the northern part the valley floors are at 600 to 800 metres while the summits are 2 500 to 3 500 metres in elevation.

FIGURE 1. Forest Regions of British Columbia

Climate is strongly influenced by the range in relief and the northwest-southeast orientation of the mountain systems. Temperatures become cooler and precipitation increases from south to north. Precipitation extremes are particularly pronounced. Mean annual precipitation in the Rocky Mountain Trench ranges from 30 to 40 cm in the south to 100 to 150 cm in the north. On the windward slopes of the Monashees and Selkirks annual precipitation is 40 to 50 cm in the south and 150 to 250 cm or more in the north. Snowfall likewise increases from south to north and is heaviest in the northwestern part of the Nelson Forest Region (Farley, 1979).

3.2. Soil Disturbance Surveys

3.2.1. Selection of Study Sites

Clearcuts logged by cable and groundskidding methods under "winter" (on snow and/or frozen ground) and "summer" (on snow-free, unfrozen ground) conditions, and on gentle to steep terrain were surveyed. High-elevation clearcuts (above 1 200 metres) were preferred. Candidate sites had been logged within the previous four years but had not received any post-harvesting treatment that might have

altered the character and/or extent of soil disturbance (eg. slash-burning, scarification, planting or grass-seeding).

Groundskidded clearcuts were stratified into three slope classes: less than 20%, 20% to 40%, and steeper than 40 percent. Cable-logged sites could not be stratified by slope as there were not enough suitable sites available.

Physical descriptions of cutovers surveyed for soil disturbance are given in Appendix II (p. 184).

3.2.2. Survey Methods

Study methods and procedures developed by Smith and Wass (1976) were adopted essentially intact so that data from the two studies would be compatible. Exposed mineral soil was selected as an index of soil disturbance (Bockheim, Ballard and Willington, 1975; Smith and Wass, 1976), and was measured using a point sampling technique (Smith and Wass, 1976). Transects were angled across the contours to intersect haul roads and skid roads (see Figure 2). When more than one transect was needed to obtain the desired number of sample points, the starting point of the second transect was

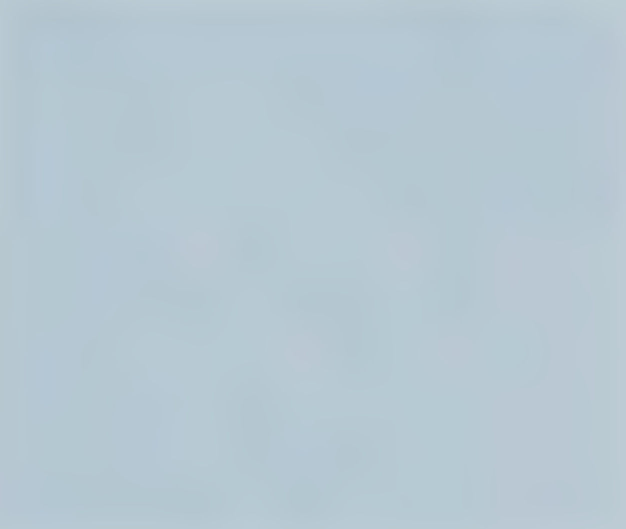
located by offsetting 50 to 100 metres from the end of the first. A compass bearing was then chosen so that the second transect would parallel or diverge from the first. Subsequent transects, if needed, were located in the same manner. Sample points were spaced two metres apart. A sampling intensity of 15 to 20 points per hectare was selected as a target, although it was exceeded on some of the smaller clearcuts. A minimum of 400, and preferably between 700 and 900, points were sampled on each clearcut.

FIGURE 2. Soil disturbance survey transects on a groundskidded clearcut.

Sample points were described according to the criteria developed by Smith and Wass (1976). Each point was characterized as "disturbed" (mineral soil exposed), "undisturbed" (mineral soil not exposed), or "other" (non-soil area). Disturbed points were identified by depth (light: 0 to 5 cm; deep: 5 to 25 cm; very deep: more than 25 cm); by source (haul road, skid road, landing, or yarding); and by location if on haul roads, skid roads or landings (sidecast, road surface, or cutbank). "Other" points included stumps, windfalls, logging slash greater than 5 cm in diameter, and rocks greater than 25 cm in diameter. A point classed as "other" but located on a disturbed surface (eg. a piece of slash on a landing) was further identified by its location.

Examples of light, deep and very deep disturbance are shown in Figure 3.

A point sample that did not fall on exposed mineral soil or meet the criteria of the "other" category was classed as "undisturbed". This included points where the duff was disturbed but the mineral soil was not exposed. Intimate mixtures of duff and mineral soil were classed as "light" soil disturbance.



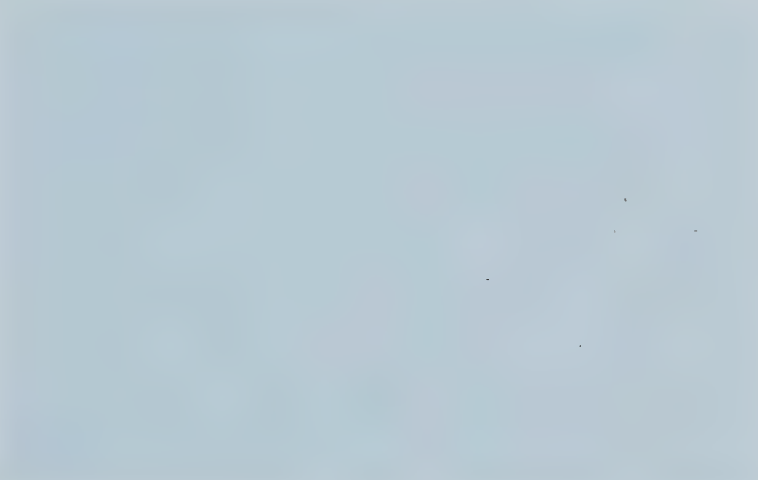


FIGURE 3. Examples of light, deep and very deep soil disturbance.

a. Light disturbance (skid road).
b. Deep disturbance (skid road).
c. Very deep disturbance (skid road).

a. Light disturbance (skid road).

b. Deep disturbance (skid road).

c. Very deep disturbance (skid road).

Soil disturbance in total or for specific sources or depth classes was expressed as a percentage by the following relationship:

$$\% \text{ disturbance} = \frac{(\text{number of disturbed sample points})}{(\text{total number of sample points})} \times 100.$$

3.2.3. Statistical Methods

Two Analysis of Variance (ANOVA) tests were applied to the soil disturbance data (Zalik, 1976). Each analysis involved a 4-way classification of the data and employed a randomized block design with uneven subgroup sizes. The basic unit of data used in the ANOVA was percent disturbance per depth class. The bulk of the survey data fell outside of the 30- to 70-percent range, so it was necessary to normalize the data by applying an arcsine $\sqrt{\text{percentage}}$ transformation, which converted percentage to degree data (Zalik, 1976). (The standard error of the estimate is strongly correlated to the size of the percentage for data outside the 30 to 70% range.) Appendix III (pp. 186 - 190) provides tables of raw and transformed data as used in these analyses.

Analysis 1 grouped the data by source of disturbance, season of logging and logging system. This analysis, which compared cable-yarded sites with groundskidded blocks, was restricted to clearcuts having average slopes steeper than 20% to reduce the disparity in terrain conditions between the two logging systems. The comparison tested for significant differences between methods and seasons of logging, as well as for differences between the two logging systems in terms of source contributions to total disturbance (ANOVA Table IV-1, Appendix IV, page 194). Analysis 2 grouped the data by slope class, source of disturbance and season of logging. This analysis tested summer and winter groundskidded sites for interactions between slope and season of logging, source of disturbance, and depth distribution (ANOVA Table IV-2, Appendix IV, page 198).

Means for all statistically-significant main effects and interactions were compared using the Newman-Kuels Range Test (Hicks, 1973). Complete Range Test analyses are presented in Appendix IV (pp. 191 - 201).

Unless stated otherwise, all results described in the following discussion are statistically significant at a 99% confidence level.

3.3. Analysis of Soil Properties on Skid Road Surfaces

3.3.1. Selection of Study Sites

The criteria used to select the two sites for this phase of the study were as follows:

(i) differing soil textures (preferably one fine-textured and the other coarse-textured);

(ii) summer-logged not less than one year and not more than three years previously;

(iii) uniform, moderate to steep slopes;

(iv) similar logging equipment (tractors) and logging layouts (systems of parallel, level to gently sloping skid roads with steep feeder roads to the landings); and

(v) evidence of mature rill erosion on skid road surfaces.

An additional consideration was the availability of water nearby in order to run infiltration tests.

3.3.2. Study Methods

(a) Selection of Soil Parameters

Emphasis was placed on measuring changes in soil properties having broad implications for regeneration and growth of

trees and surface soil erosion. The properties chosen for this analysis were:

- pH of soil;
- carbonate content of soil;
- organic matter content;
- total carbon content;
- bulk density of soil;
- particle-size distribution of soil; and
- infiltration capacity of soil.

(b) Field Methods

Five suitable skid roads were randomly selected on each site from those intersected by a transect running uphill from the bottom of the clearcut. (A suitable skid road had level to gentle gradients (0 to 10%) and no exposed bedrock in the profile.) The skid road was cross-sectioned and divided into six zones (see Figure 4):

(i) undisturbed ground surface (above the cut bank);
(ii) cut bank;
(iii) skid road surface -- inner track;
(iv) skid road surface -- center;
(v) skid road surface -- outer track; and
(vi) sidecast (or fill) slope.

A core sampler 7.6 cm in diameter was used to collect soil cores 10 cm in length for bulk density determinations for

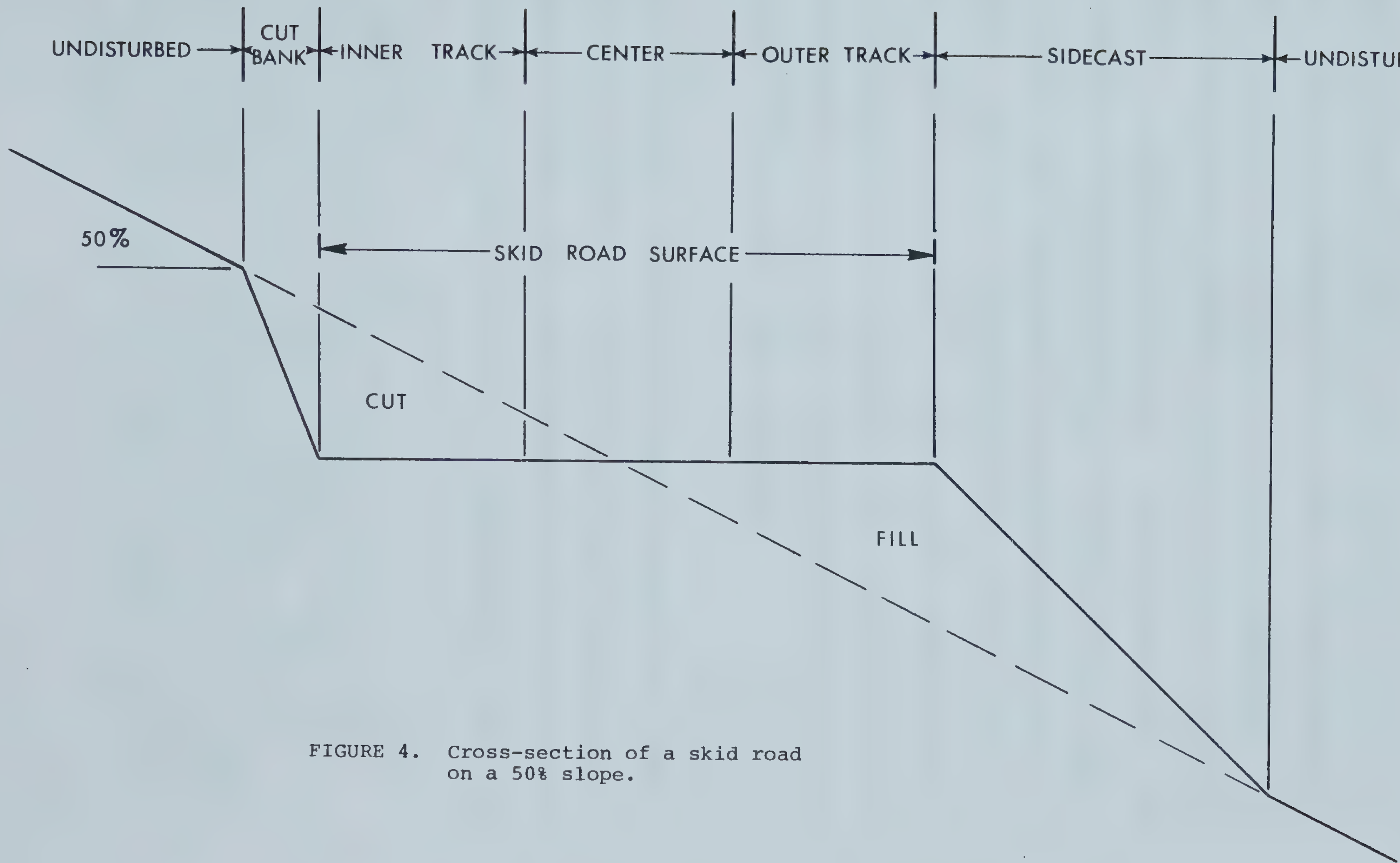


FIGURE 4. Cross-section of a skid road on a 50% slope.

each of the six zones.[1] Samples were bagged and sealed on collection. Soil pH, carbonate content and organic matter content were sampled at three sites -- the undisturbed surface, the base of the cutbank, and on the inner track of the skid road -- using the bulk density core samples for the necessary laboratory determinations. Estimates of pH and carbonate content were also made in the field, the former using a litmus paper test kit and the latter with a 10% solution of hydrochloric acid. Finally, soil samples for particle-size analysis were taken from the undisturbed soil surface, the base of the cutbank (C-horizon) and the surface five centimetres of the skid road surface.

Short-term infiltration rates of the undisturbed soil surface and the inner track area of the skid road surface were measured using a double-ring infiltrometer apparatus similar to that described by Lewis (1968). (It differed in that the

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[1]An alternative method of determining bulk density was also tested. A relatively flat area was levelled, then a small hole or trench was excavated with a trowel and the excavated material retained for weighing. The pit was lined with light-gauge plastic and the volume of water required to fill the hole was measured and recorded. This method was easier to use and more reliable than the core sampler in very coarse-textured soils, but in medium- to fine-textured soils both techniques produced acceptable results. The core sampler, being faster to use, was therefore preferred.

inner and outer rings used in this study were 10 and 18 inches, respectively, compared to 12 and 20 inches in Lewis' study.) The tests were originally intended to be three-hour constant-head tests but this proved not to be feasible. Lack of nearby water supplies and lack of road access to the study sites limited the amount of water available for each test, while the perviousness of the soil determined the duration of each run. On the most pervious soils this was less than 20 minutes, not long enough to provide a meaningful value of infiltration capacity which in normal usage is defined for periods of one hour or longer.

However, the variable of interest in this study was the relative difference in infiltration rate between on-road and off-road sites, not an absolute value for each. A standard procedure was therefore developed to permit this comparison. After removing litter and duff layers and preparing a level surface (necessary for off-road sites on steep sideslopes), the two rings were driven into the ground to a depth of about 10 centimetres. Water was first applied to the outer ring and then to the inner ring, to a depth of 15 to 20 centimetres. Water was added occasionally to the outer ring while sediment was allowed to settle for 10 minutes in the inner ring. Then the inner ring was filled to depth of 25 cm

above the soil surface. Head loss was measured at 2½-minute intervals for periods of up to 2 hours on the least pervious soils. On a few rapidly-drained sites it was necessary to refill the inner ring occasionally when the water level had dropped to 10 centimetres. During the timed runs the water level in the outer ring was maintained at approximately the same level as the inner ring. This process was continued until the water supply was exhausted. The run of shortest duration, which set the basis for comparison between on-road and off-road sites, was 15 minutes.

It was felt this procedure would overstate infiltration rates because the high pressure head would exceed natural driving forces. Differences between on-road and off-road sites would be somewhat conservative, however, if (as expected) water drained more rapidly on off-road sites: over the duration of the run off-road sites would experience an overall lower average driving force through greater head loss.

Rill erosion was documented on all skid roads intersected by the transect. Each rill was measured from its initiation point to its outlet and broken down into segments of uniform slope. Rill width and depth was recorded for the beginning and end of each segment.

(c) Laboratory Methods

Soil pH was estimated in the field and measured potentiometrically in a water-soil solution in the laboratory according to methods described by McMullan (1971). Organic carbon was determined by the dry combustion method (McKeague, 1976) and cross-checked during carbon content analysis by sulphurous acid treatment (McMullan, 1972) followed by freeze-drying and dry combustion. Soil particle-size distributions were determined by dry-sieve analysis followed by hydrometer analysis of the minus-#40 fraction (Bowles, 1970).

3.3.3. Statistical Methods

Analysis of Variance tests were applied to each of the soil parameters to test for differences within the skid road cross-section as well as between study sites (see Appendix V, p. 202). The complexity of the block design depended upon the number of sampling locations being compared, which ranged from two to six. Newman-Kuels Range Test and the Student's t-test were applied to determine differences between means (Hicks, 1973; Walpole, 1968).

4. RESULTS

4.1. Descriptions of Study Areas

4.1.1. Soil Disturbance Surveys

Thirty-one clearcut blocks were surveyed. Twenty-five were logged with conventional groundskidding systems (mostly tractors) and six with cable (highlead and grapple-yarding) systems (see Appendix VI, p. 212, for fuller descriptions of highlead, grapple and skyline yarding systems). At least three clearcuts were surveyed in each grouping (season/slope groupings for groundskidding systems, season only for cable systems). Suitable groundskidded clearcuts were more abundant than cable-logged clearcuts. Winter-logged groundskidded clearcuts were most plentiful, reflecting the dominant role of winter logging in the Nelson Forest Region.

Locations of the sampled clearcuts are shown in Figure 5. Physical descriptions of each site are summarized in Appendix II (p. 184).

Clearcut elevations ranged from 910 to 1 970 metres and averaged 1 360 metres. Average elevations of groundskidded

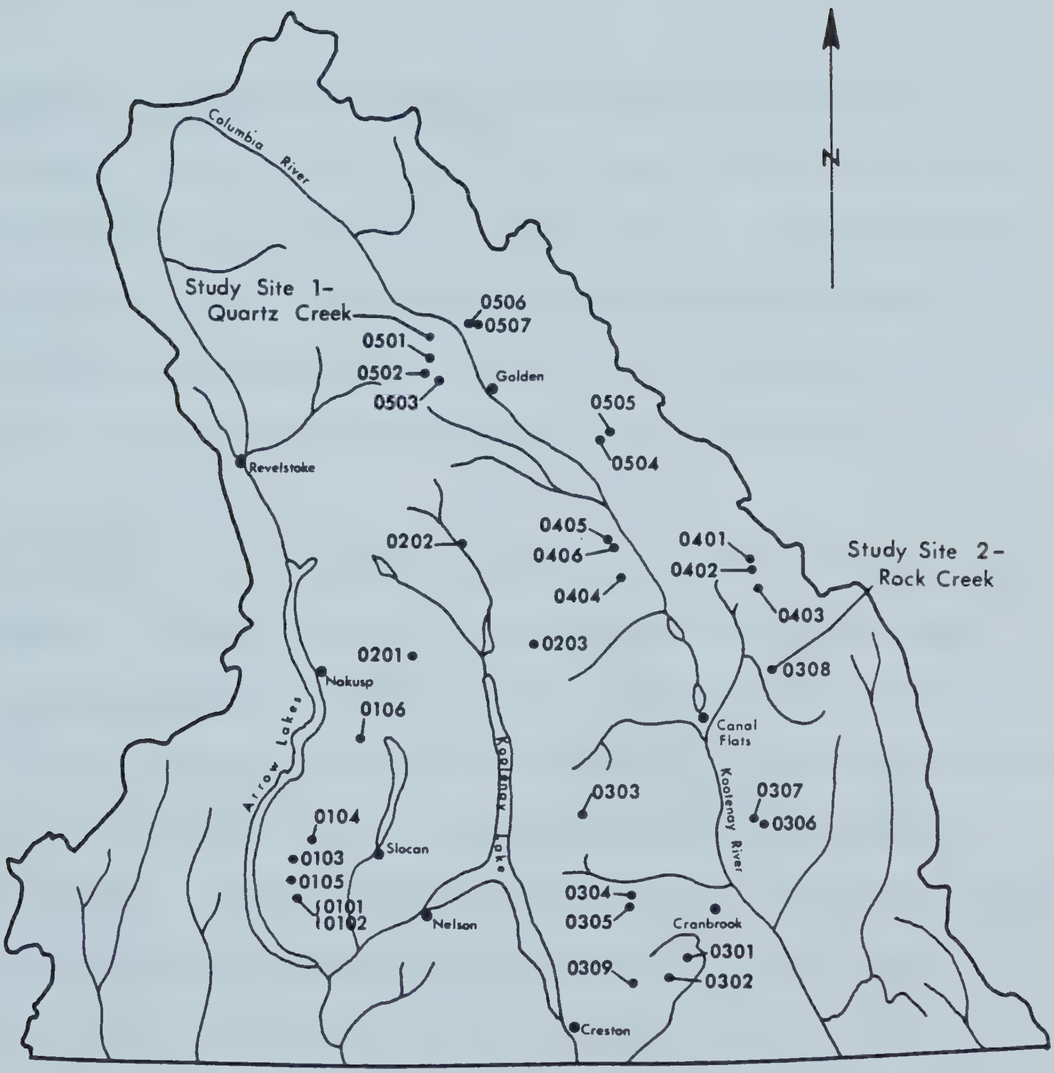

FIGURE 5. Locations of clearcuts surveyed for soil disturbance and skid road characteristics, Nelson Forest Region.

clearcuts were 1 390 metres for summer-logged sites and 1 360 metres for winter-logged sites. Elevations of cable-logged clearcuts averaged 1 200 metres for summer and 1 400 metres for winter.

The Englemann Spruce/Subalpine Fir biogeoclimatic zone (Krajina and Brooke, 1970) was well-represented due to the preference for high-elevation study areas. Clearcuts were also sampled in the Interior Douglas-Fir and Interior Western Hemlock zones, and in transitional complexes between these and the Englemann Spruce/Subalpine Fir zone.

Average slopes for individual clearcuts ranged from 5.2 to 74.2 percent. Slope ranges and averages for winter and summer groundskidded clearcuts were similar (5.2 to 52.4% with a class average of 27.0% for winter-logged blocks, and 12.8 to 48.3% with a class average of 29.8% for summer-logged blocks). Cable-logged clearcuts had a narrower range and higher average slope gradients (32.1 to 49.4% and an average of 40.8% for winter cable-logged blocks, and 50.0 to 74.2% with an average of 61.6% for summer cable-logged blocks).

4.1.2. Skid Road Surveys

Two clearcuts having similar terrain features and logging histories but dissimilar soil textures (one gravelly sandy loam and one sandy silty loam) were selected for this phase of the study. Their locations are shown in Figure 6.

Study Site #1 (Figure 6a) was located in Quartz Creek, in the northern Purcell Mountains approximately 30 kilometres west of Golden, British Columbia. Its biogeoclimatic status appeared to be transitional between the Interior Western Hemlock (IWH) and Englemann Spruce/Subalpine Fir (ESSF) zones, suggesting a 4- to 5-month growing season, mild to cool summers and relatively long, cold winters, with moderate to high annual precipitation (750 to 1 500 mm, with much of it falling as snow) (Krajina and Brooke, 1970). Underlying bedrock formations were assigned to the Proterozoic (Jackson, 1976), and consisted of metamorphosed shales and sandstones (quartzites) with some igneous outcroppings.

The study block occupied lower to middle slope positions, had an east to northeast aspect, and an average elevation of 1 650 metres (about 5,400 feet). Slopes ranged from 30% in

a. Quartz Creek.

b. Rock Creek.

FIGURE 6. Study sites for soil properties evaluation.

a. Quartz Creek.
b. Rock Creek.

lower sections to over 70% near the upper boundary, and averaged about 45 percent.

Soils were composed of shallow, moderately acidic, medium- to coarse-textured colluvium over compact morainal material on lower slopes, grading to thin and shallow colluvial soils directly over bedrock on steeper mid to upper slopes. The soils were tentatively classified as (Podzolic) Gray Luvisols (Canada Soil Survey Committee, 1978).

The study block was tractor-logged in the summer of 1975 and slashburned in late 1976.

Study Site #2 (Figure 6b), located in the White River drainage approximately 25 kilometres east-northeast of Canal Flats, British Columbia, was set in the Eastern Marginal Belt of the Canadian Cordillera, just within the Main Ranges sub-province of the Rocky Mountains (Jackson, 1976; Henderson, 1954).

The study area occupied an open mid-slope position between two tributary creeks (Rock and Elk Creeks) on the east side of the White River. The clearcut had a west aspect and an

average elevation of 1 275 metres (4,200 feet). Slopes ranged from 30% to 120% and averaged 47.5 percent. Bedrock consisted of calcareous siltstones and was probably part of the McKay Group, a series of alternating shales and limestones of Late Cambrian to Ordovician age (Henderson, 1954). Its biogeoclimatic setting appeared to be within the Interior Douglas-fir (IDF) zone, inferring a drier and warmer regime than Quartz Creek (Krajina and Brooke, 1970).

Rock Creek soils were shallow, strongly alkaline, medium- to fine-textured colluvium over a slightly to moderately weathered calcareous sedimentary siltstone. The soils were tentatively classified as Orthic Eutric Brunisols (Canada Soil Survey Committee, 1978).

This clearcut was included in the soil disturbance surveys as Block 0308, Rock Creek (see Table 1, p. 61). The area was logged with small crawler tractors in the summer of 1975. It was not slashburned.

4.2. Results of Soil Disturbance Surveys

4.2.1. General

Table 1 and Figure 7 summarize the soil disturbance data for the 31 clearcuts. ANOVA results for the two analyses are presented in Table 2 (comparison of cable versus groundskidding systems on slopes greater than 20%) and Table 3 (comparison of summer versus winter groundskidding on slopes of less than 20%, 20% to 40%, and greater than 40%). The most significant points are:

(i) From Table 1:

1. Groundskidding systems caused 16 to 18% more soil disturbance than cable systems for comparable logging seasons;

2. Summer logging operations caused 5 to 7% more soil disturbance than winter logging operations for comparable logging systems;

3. Distributions of soil disturbance by source are similar for summer and winter groundskidding operations but differ substantially for summer and winter cable-logging operations;

4. Haul road-related disturbance is very high on winter cable-logged sites (16.6%) compared to summer and winter groundskidded sites (8.3 and 7.6%, respectively) and summer cable-logged sites (9.0%);

5. Landing-related disturbance is more than twice as high on summer and winter groundskidded sites (5.1 and 4.3%, respectively) as on summer and winter cable-logged sites (1.3 and 0.5%, respectively);

Table 1. Summary of soil disturbance (in percent) on surveyed clearcuts.[1]

BLOCK NUMBER	BLOCK LOCATION	SOURCE OF DISTURBANCE: HAUL ROADS	LANDINGS	SKID ROADS	YARDING	TOTAL SOIL DISTURBANCE
1. Cable Logging, Summer						
0103	Brodie Creek	9.5%	0.0%	0.5%	11.5%	21.5%
0309	Kid Creek	8.5	2.3	1.5	14.8	27.1
0404	Campbell Creek	9.1	1.6	6.4	22.8	39.9
	Averages	9.0	1.3	2.8	16.4	29.5
2. Cable Logging, Winter						
0102	Grizzly Creek	16.6	0.0	6.4	3.2	26.2
0106	Shannon Creek	9.7	0.0	1.7	0.9	12.3
0301	Lamb Creek	23.5	1.4	0.0	3.5	28.4
	Averages	16.6	0.5	2.7	2.5	22.3
3. Groundskidding, Summer						
0101	Grizzly Creek	12.1	1.5	11.0	4.2	28.8
0201	Poplar Creek	4.9	0.3	27.2	1.6	34.0
0302	Lamb Creek	0.7	1.5	24.0	3.7	29.9
0303	Dewar Creek	3.9	4.3	32.0	3.4	43.6
0304	Hellroaring Creek	12.0	11.9	38.1	1.9	63.9
0308	Rock Creek	5.6	0.1	37.4	4.4	47.5
0403	Lower Palliser River	6.1	6.0	12.9	5.6	30.6
0503	Quartz Creek	9.5	18.0	36.4	1.1	65.0
0506	Copper Creek	10.8	5.0	33.3	1.3	50.4
0507	Copper Creek	17.3	2.5	36.0	4.9	60.7
	Averages	8.3	5.1	28.8	3.2	45.4
4. Groundskidding, Winter						
0104	Hoder Creek	6.6	0.0	22.9	3.6	33.1
0105	Grizzly Creek	11.3	0.0	33.9	5.5	50.7
0202	Duncan River	11.3	1.2	26.9	10.7	50.1
0203	Glacier Creek	12.0	0.0	15.4	3.2	30.6
0305	Hellroaring Creek	8.3	8.3	32.0	2.5	51.1
0306	Nicol Creek	10.3	6.3	34.7	0.9	52.2
0307	Nicol Creek	9.4	0.9	31.7	2.6	44.6
0401	Lower Palliser River	8.1	11.1	10.9	13.9	44.0
0402	Lower Palliser River	10.3	4.5	37.3	0.3	52.6
0405	Hall Lakes	2.8	9.2	6.3	7.3	25.6
0406	Hall Lakes	4.0	3.5	2.3	3.9	13.7
0501	Quartz Creek	7.2	8.0	23.1	2.3	40.6
0502	Quartz Creek	1.0	3.6	30.0	0.3	34.9
0504	Dainard Creek	10.1	4.9	28.9	1.9	45.8
0505	Dainard Creek	1.9	3.4	30.2	1.0	36.5
	Averages	7.6	4.3	24.4	4.0	40.4

[1] $\% \text{ soil disturbance} = \frac{\text{(number of disturbed sample points)}}{\text{(total number of sample points)}} \times 100$

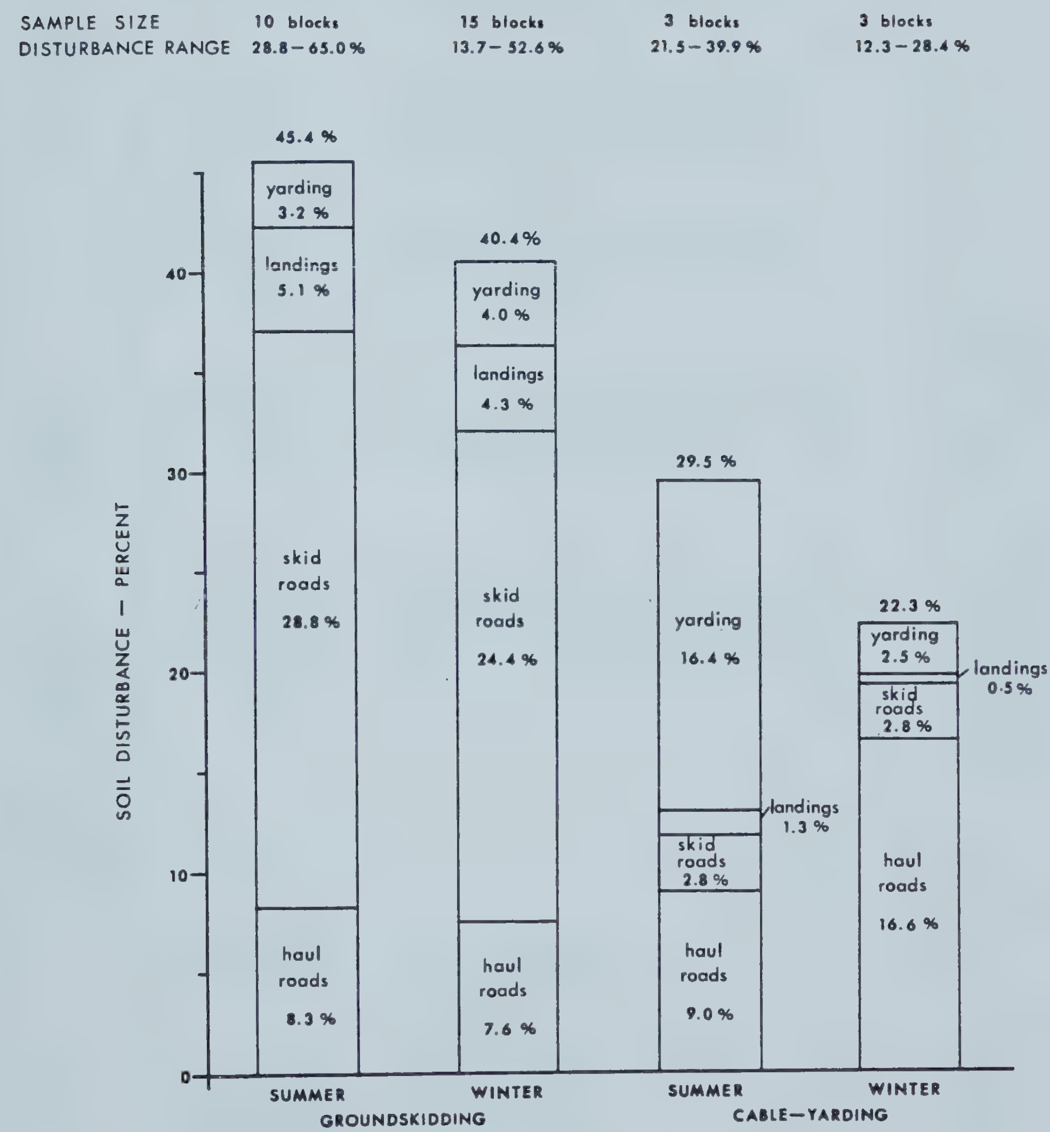

FIGURE 7. Contribution by source to average total soil disturbance for summer- and winter-logged groundskidded and cable-yarded sites.

Table 2. Analysis of Variance - cable yarding versus groundskidding on slopes >20%.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F	$F_{0.05}$	$F_{0.01}$	SIGNIFICANCE[1]
1. Main Effects							
Method of Logging (M)	1	380.45	380.45	32.91	3.84	6.63	**
Season of Logging (Se)	1	5.88	5.88	0.51	3.84	6.63	N.S.
Source of Disturbance (Sd)	3	4,351.65	1,450.55	125.48	2.60	3.78	**
Depth of Disturbance (De)	2	346.45	173.23	14.99	3.00	4.61	**
2. Interactions							
Method x Season (M x Se)	1	38.16	38.16	3.30	3.84	6.63	N.S.
Method x Source (M x Sd)	3	2,202.76	734.25	63.52	2.60	3.78	**
Method x Depth (M x De)	2	132.48	66.24	5.73	3.00	4.61	**
Season x Source (Se x Sd)	3	175.46	58.49	5.06	2.60	3.78	**
Season x Depth (Se x De)	2	28.35	14.18	1.23	3.00	4.61	N.S.
Source x Depth (Sd x De)	6	2,773.26	462.21	39.98	2.10	2.80	**
M x Se x Sd	3	68.00	22.67	1.96	2.60	3.78	N.S.
M x Se x De	2	26.93	13.47	1.17	3.00	4.61	N.S.
M x Sd x De	6	138.64	23.11	2.00	2.10	2.80	N.S.
Se x Sd x De	6	130.88	21.81	1.89	2.10	2.80	N.S.
M x Se x Sd x De	6	58.87	9.81	0.85	2.10	2.80	N.S.
3. Error	216	2,497.00	11.56				
4. Total	263						

[1]Levels of Significance: ** - Significant at 99% level.
* - Significant at 95% level.
N.S. - Not Significant at 95% level.

Table 3. Analysis of Variance - summer versus winter groundskidding on slopes <20%, 20% to 40%, and >40%.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F	$F_{0.05}$	$F_{0.01}$	SIGNIFICANCE[1]
1. Main Effects							
Season of Logging (M)	1	18.99	18.99	1.23	3.84	6.63	N.S.
Slope Class (Se)	2	1.18	0.59	0.04	3.00	4.61	N.S.
Source of Disturbance (Sd)	3	6,309.03	2,103.01	136.29	2.60	3.78	**
Depth of Disturbance (De)	2	211.03	105.52	6.84	3.00	4.61	**
2. Interactions							
Season x Slope (Se x S1)	2	14.43	7.22	0.47	3.00	4.61	N.S.
Season x Source (Se x Sd)	3	35.31	11.77	0.76	2.60	3.78	N.S.
Season x Depth (Se x De)	2	40.95	20.48	1.33	3.00	4.61	N.S.
Slope x Source (S1 x Sd)	6	752.24	125.37	8.13	2.10	2.80	**
Slope x Depth (S1 x De)	4	438.72	109.68	7.11	2.37	3.32	**
Source x Depth (Sd x De)	6	2,330.48	388.41	25.17	2.10	2.80	**
Se x S1 x Sd	6	194.02	32.34	2.10	2.10	2.80	N.S.
Se x S1 x De	4	82.54	20.64	1.34	2.37	3.32	N.S.
Se x Sd x De	6	24.73	4.12	0.27	2.10	2.80	N.S.
S1 x Sd x De	12	362.34	30.20	1.96	1.75	2.18	*
Se x S1 x Sd x De	12	131.81	10.98	0.71	1.75	2.18	N.S.
3. Error	228	3,518.98	15.43				
4. Total	299						

[1]Levels of Significance:
** - Significanct at 99% level.
* - Significanct at 95% level.
N.S. - Not significant at 95% level.

6. Skid road-related disturbance is almost ten times as high on summer and winter groundskidded sites (28.8 and 24.4%, respectively) as on summer and winter cable-logged sites (2.8 and 2.7%, respectively);

7. Yarding-related disturbance is very high on summer cable-logged sites (16.4%) compared to summer and winter groundskidded sites (3.2 and 4.0%, respectively) and winter cable-logged sites (2.5%);

8. Variability in disturbance within a given logging method/logging season category, either in total or in one or more of its components, is high. The magnitudes of within-group differences generally exceed between-group differences.

(ii) From Table 2:

1. Three of four variables - method of logging, source of disturbance, and depth of disturbance - have significant effects on levels of soil disturbance;

2. All simple (first-order) interactions that are combinations of the above variables are also significant;

3. Season of logging does not significantly affect soil disturbance (although the first-order interaction involving season of logging and source of disturbance is significant).

(iii) From Table 3:

1. Two of four main effects - source of disturbance and depth of disturbance - significantly affect soil disturbance levels on groundskidded clearcuts (see also Table 2);

2. Three of six simple interactions, involving slope class and source and depth of disturbance, are significant;

3. Slope class is not significant as a main effect but is significant in simple interactions involving source and depth of disturbance;

4. Season of logging does not significantly affect soil disturbance levels at either the main effect or interaction levels.

4.2.2. Effect of Logging Method on Soil Disturbance

For the clearcuts surveyed in this study, logging with groundskidding systems on slopes greater than 20% caused significantly more soil disturbance than did logging with cable systems (see Table 2). Soil disturbance on six cable-yarded clearcuts averaged 29.5% compared to 42.4% on 25 groundskidded clearcuts. Thus the results of this survey are consistent with the findings of other researchers, supporting the widely-held view that groundskidding systems cause more soil disturbance than cable systems.

Average total soil disturbance for all groundskidded clearcuts, regardless of slope, was only slightly less than for groundskidded clearcuts on slopes greater than 20 percent (42.4% versus 43.8%). It therefore seems likely that soil disturbance is significantly greater on groundskidded than

on cable-yarded clearcuts for the full range of slopes sampled.

The 16 to 18% difference between the logging systems is primarily explained by skid roads and, to a much lesser extent, by landings. However, higher-than-average haul road disturbance on winter cable-logged sites and yarding disturbance on summer cable-logged sites have compensated somewhat for the larger skid road differences.

4.2.3. Effect of Season of Logging on Soil Disturbance

On the cutovers surveyed in this study less soil disturbance was recorded on winter-logged than on summer-logged areas for both logging systems. For groundskidded blocks an average difference of 5% was recorded: 40.4% for winter versus 45.4% for summer. Minor decreases in soil disturbance associated with haul roads, landings and skid roads combined to create this difference. On cable-yarded blocks a slightly larger difference of 7% was noted: 22.3% for winter versus 29.5% for summer. However, the reduction on cable-yarded sites could not be attributed to any particular source (see Table 1).

At first glance these differences seem to support the popular opinion that season of logging is a major factor affecting the level of soil disturbance. The statistical analyses, however, do not support this view. In this study season of logging did not significantly influence soil disturbance levels on either groundskidded or cable-yarded blocks. In fact, season of logging was most noteworthy for its virtually complete lack of influence on any aspect of logging method/soil disturbance relationships.

This lack of seasonal differentiation probably reflected the cumulative effect of several variables. I feel the following were contributing factors in this study:

1. Criteria for stratifying blocks into summer-logged and winter-logged units were too broad. Basically, a cutover was classed as winter-logged if it had been logged between the periods of freeze-up in the fall and break-up in the spring of the following year. This did not effectively account for variations in snowpack depth from shallowest in early winter to deepest in spring.

2. The sample was distributed widely over a region noted for its extremes in snowfall, from very heavy snowfalls in the northwest to relatively light snowfalls in the south and east.

3. A wide range in operational factors such as type and size of groundskidding equipment, skid road densities, skidding patterns and cutblock layouts was not accounted for when selecting candidate sites.

4. A significant proportion of total soil disturbance was influenced only slightly, if at all, by season of logging. For example, haul roads and landings, which together accounted for more than one-quarter of all disturbance on groundskidded sites and more than half on cable-yarded sites, were usually built well in advance of actual logging and mostly in the summer. In some cases skid roads were also built well before the areas were logged.

5. Haul roads, landings and skid roads required larger excavations as slopes became steeper. Consequently the protective value of a snowpack may have been reduced or negated when slopes became steep enough to require operators to build skid trails.

It should be noted that one interaction involving season of logging and source of disturbance was significant (see Table 2). A Newman-Kuels Range Test applied to the eight possible means (2 seasons X 4 sources) showed summer logging caused significantly more yarding disturbance than winter logging. This difference almost certainly reflects the high level of yarding disturbance associated with summer cable logging, since in the second analysis yarding-related disturbance did not differ significantly between summer and winter ground-skidding operations (see Table 3). Yarding-related disturbance on summer cable-yarded units constituted more than half the total disturbance but accounted for one-tenth or less in the winter cable and summer and winter groundskidding categories.

However, it is unlikely that the higher levels of yarding disturbance on summer cable-logged sites were entirely seasonal in nature. Blocks 0309 (Kid Creek) and 0404 (Campbell Creek) both had dry southerly exposures, very thin duff layers and relatively steep slopes. Coupled with the lack of a protective snowpack and poor deflection due to the steep, uniform slopes, yarding easily scraped away the duff to expose mineral soil. Block 0103 (Brodie Creek), with deeper duff layers and better deflection, had comparatively less yarding-related disturbance. In contrast, logging and site conditions on the winter cable-logged clearcuts were much more favourable: (1) Two of the units were logged with mobile swing-type yarders which used the haul road as a log deck. This distributed yarding disturbance more evenly over the clearcut. (2) A deep snowpack at the time of yarding protected the soil surface on Block 0106 (Shannon Creek). (3) Duff layers were deeper and deflection generally better on the winter-logged units.

4.2.4. Effect of Slope on Soil Disturbance

Since cable-logged blocks occupied a relatively narrow range of steep slopes, only groundskidded blocks were analyzed for slope effects.

The ten summer-logged and fifteen winter-logged blocks were stratified into three slope classes: less than 20%, 20 to 40%, and steeper than 40 percent. Table 4 summarizes total soil disturbance for summer and winter operations by slope class, and Figure 8 plots the resulting trends (including

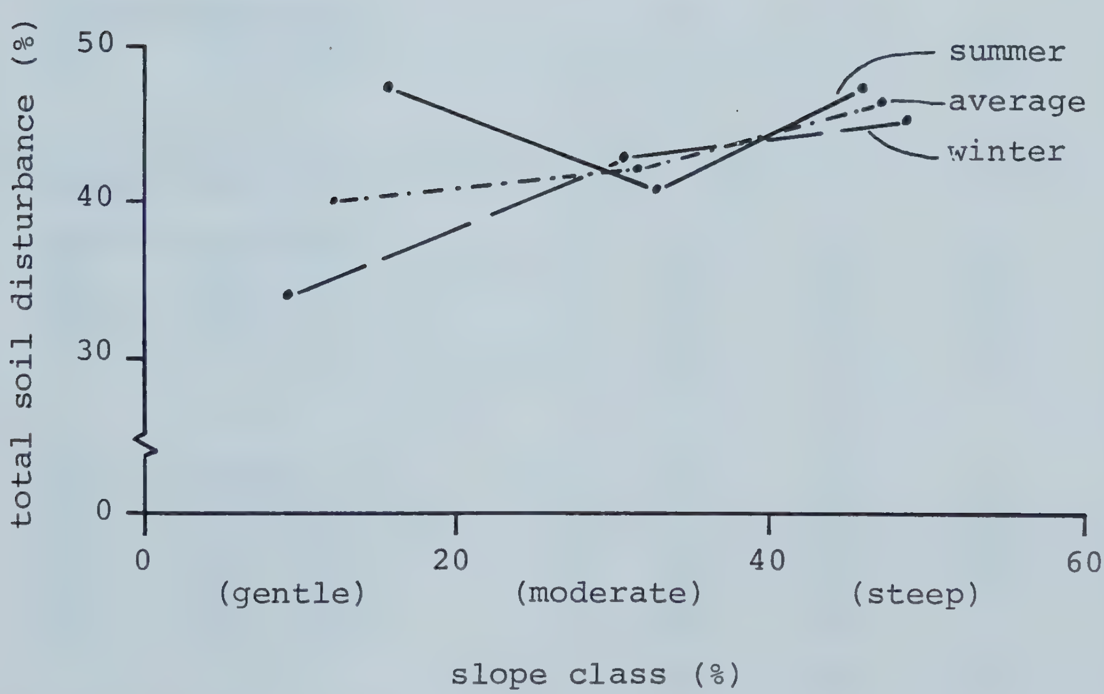

FIGURE 8. Plot of total soil disturbance against slope class for summer and winter groundskidded sites.

Table 4. Trends in soil disturbance with increasing slope on summer and winter groundskidded clearcuts.

BLOCK NUMBER	BLOCK LOCATION	SOURCE OF DISTURBANCE HAUL ROADS	SKID ROADS	LANDINGS	LOGGING	TOTAL DISTURBANCE
1. Groundskidding, Summer						
Slopes less than 20%						
0302	Lamb Creek	0.7%	24.0%	1.5%	3.7%	29.9%
0304	Hellroaring Creek	12.0	38.1	11.9	1.9	63.9
0403	Lower Palliser River	6.1	12.9	6.0	5.6	30.6
0503	Quartz Creek	9.5	36.4	18.0	1.1	65.0
	Averages	7.1	27.9	9.4	3.1	47.4
Slopes 20% to 40%						
0101	Grizzly Creek	12.1	11.0	1.5	4.2	28.8
0303	Dewar Creek	3.9	32.0	4.3	3.4	43.6
0506	Copper Creek	10.8	33.3	5.0	1.3	50.4
	Averages	8.9	25.4	3.6	3.0	40.9
Slopes greater than 40%						
0201	Poplar Creek	4.9	27.2	0.3	1.6	34.0
0308	Rock Creek	5.6	37.4	0.1	4.4	47.5
0507	Copper Creek	17.3	36.0	2.5	4.9	60.7
	Averages	9.3	33.5	1.0	3.6	47.4
2. Groundskidding, Winter						
Slopes less than 20%						
0202	Duncan River	11.3	26.9%	1.2%	10.7%	50.1%
0401	Lower Palliser River	8.1	10.9	11.1	13.9	44.0
0405	Hall Lakes	2.8	6.3	9.2	7.3	25.6
0406	Hall Lakes	4.0	2.3	3.5	3.9	13.7
0505	Dainard Creek	1.9	30.2	3.4	1.0	36.5
	Averages	5.6	15.3	5.7	7.3	34.0
Slopes 20% to 40%						
0203	Glacier Creek	12.0	15.4	0.0	3.2	30.6
0305	Hellroaring Creek	8.3	32.0	8.3	2.5	51.1
0306	Nicol Creek	10.3	34.7	6.3	0.9	52.2
0307	Nicol Creek	9.4	31.7	0.9	2.6	44.6
0501	Quartz Creek	7.2	23.1	8.0	2.3	40.6
0502	Quartz Creek	1.0	30.0	3.6	0.3	34.9
0504	Dainard Creek	10.1	28.9	4.9	1.9	45.8
	Averages	8.3	28.0	4.6	2.0	42.8
Slopes greater than 40%						
0104	Hoder Creek	6.6	22.9	0.0	3.6	33.1
0105	Grizzly Creek	11.3	33.9	0.0	5.5	50.7
0402	Lower Palliser River	10.3	37.3	4.5	0.3	52.6
	Averages	9.4	31.4	1.5	3.1	45.5

averages for combined summer and winter operations). On summer-logged sites soil disturbance was similar on gentle slopes and steep slopes (47.4%), and less on moderate slopes (40.9%). The lesser amount on moderate slopes was probably a function of the small sample size rather than a real effect. By comparison, total soil disturbance increased with increasing slope on winter-logged sites.

Some trends are apparent between source of disturbance and slope (see Table 4):

1. Haul road-related disturbance increases gradually with increasing slope and consistently accounts for 15 to 20% of total soil disturbance.

2. Landing-related disturbance decreases substantially with increasing slope, from about 20% of total disturbance on gentle slopes to 3% or less on steep slopes.

3. Skid roads constitute the largest single source of soil disturbance regardless of slope steepness (more than 50% of total soil disturbance in all but one class). In general, skid road disturbance increases as slope steepness increases.

4. With one exception, yarding constitutes a relatively constant 2 to 3% of total disturbance.

Winter-logged groundskidded sites on gentle slopes had about double the level of yarding disturbance of all other logging season/slope groupings (7.3% as compared to 2.0 to 3.6%).

Probably some of the disturbance attributed to yarding on gently-sloping winter-logged sites actually represents lightly-used skid trails. If so, the level of skid road-related disturbance (now substantially lower than for all other groupings) would be higher, and the level of yarding-related disturbance would be in closer agreement with the other groupings.

Despite the apparent trends, slope steepness did not, by itself, influence significantly total soil disturbance on the groundskidded clearcuts surveyed in this study. The differences indicated by these trends are minor, compared to the large ranges in total soil disturbance that are common to all logging season/slope class groupings. This high variability suggests that factors other than slope steepness exert a controlling influence on extent of soil disturbance.

However, other parameters of soil disturbance (specifically its distribution by source and depth classes) are apparently strongly influenced by slope steepness (see Table 3). Relationships between slope and source and depth of disturbance are discussed in detail in Section 4.2.5., Depth of Disturbance, and Section 4.2.6., Source of Disturbance.

4.2.5. Depth of Disturbance

Figure 9 summarizes total soil disturbance by depth class for the 25 groundskidded and 6 cable-yarded clearcuts. Overall, groundskidding caused more very deep and deep soil disturbance than cable yarding, probably as a result of the additional disturbance contributed by skid roads.[1] On slopes greater than 20%, groundskidding generated more very deep than deep disturbance, and in turn more deep than light disturbance. In contrast, cable yarding systems did not generate significantly greater levels of one depth class than of any other. This was attributed to the small sample size and high variability among the cable-logged clearcuts.

Depth distributions for summer and winter groundskidded clearcuts were similar, with the exception that more very deep disturbance occurred on summer-logged than on winter-logged blocks (19.2% versus 13.6%). Deep and very deep disturbance dominated the depth profiles for both seasons, and was thought to be due to haul road, landing and skid road construction. (Relationships between source and depth

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[1]See Appendix IV, Table IV-1d, p. 196.

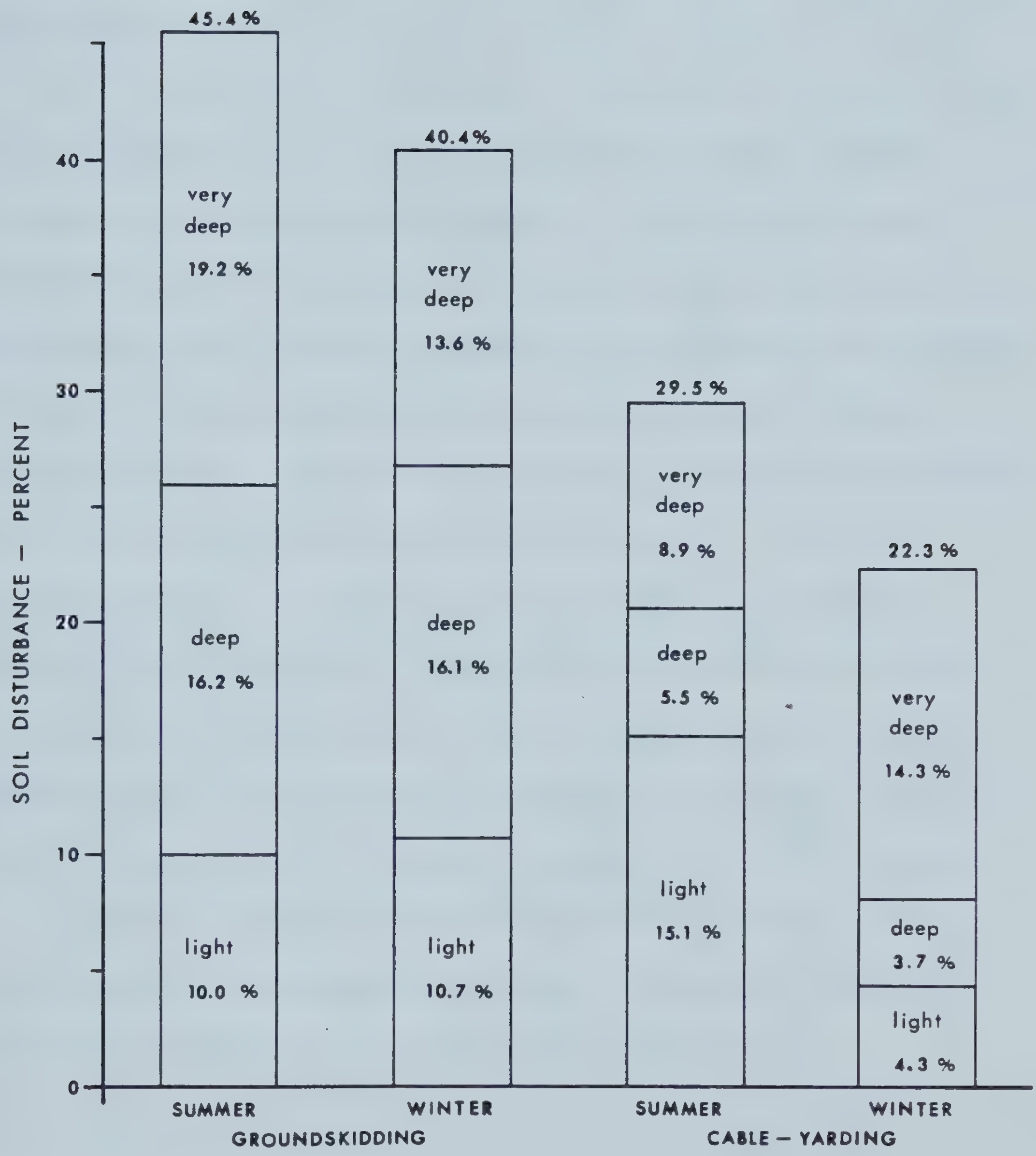

FIGURE 9. Distribution of average total soil disturbance by depth class, all sources, for summer- and winter-logged groundskidded and cable-yarded sites.

of disturbance are discussed in detail in Section 4.2.6., Source of Disturbance.)

Depth distributions for summer and winter cable-yarded blocks were substantially different. Light disturbance dominated the profile for summer-logged sites while at the other extreme very deep disturbance constituted the largest proportion of soil disturbance on winter-logged sites. There were obvious parallels between the depth distributions (Figure 9) and source distributions (Figure 7) for the cable-yarded sites. A high level of light disturbance appeared to correspond to a high level of yarding disturbance on summer-logged sites, while a high level of very deep disturbance appeared to be related to a high level of haul road disturbance on winter-logged sites. These parallels suggested strong source/depth interactions, which were confirmed in subsequent analyses. (Again these are described in detail in the following section.)

(a) <u>Effect of Slope on Depth Distributions</u>

Table 5 summarizes soil disturbance by depth class and slope class for summer and winter groundskidded sites.

Over the full range of slopes examined the greatest amounts of disturbance occurred in the deep and very deep classes (Figure 10). Seasonal differences were minor, although on average there was less very deep disturbance on winter-logged blocks (13.6%) than on summer-logged blocks (19.2%).

The interaction of slope class and depth of disturbance was highly significant (see Table 3). A Newman-Kuels Range Test

Table 5. Distribution of soil disturbance by slope and depth class for summer and winter groundskidded clearcuts.

SEASON OF LOGGING	SLOPE CLASS	DEPTH CLASS			TOTAL SOIL DISTURBANCE
		LIGHT	DEEP	VERY DEEP	
SUMMER	<20%	12.0%	19.3%	16.1%	47.4%
	20-40%	9.6	14.8	16.6	41.0
	>40%	7.7	13.4	26.2	47.4
WINTER	<20%	15.3%	13.1%	5.8%	34.2%
	20-40%	7.8	18.8	16.3	42.9
	>40%	10.1	14.6	20.6	45.3

showed a significant increase in the quantity of very deep disturbance from gentle to steep slopes (significant at a 5% level of confidence)[2]. Light and deep disturbance showed no significant trend with slope.

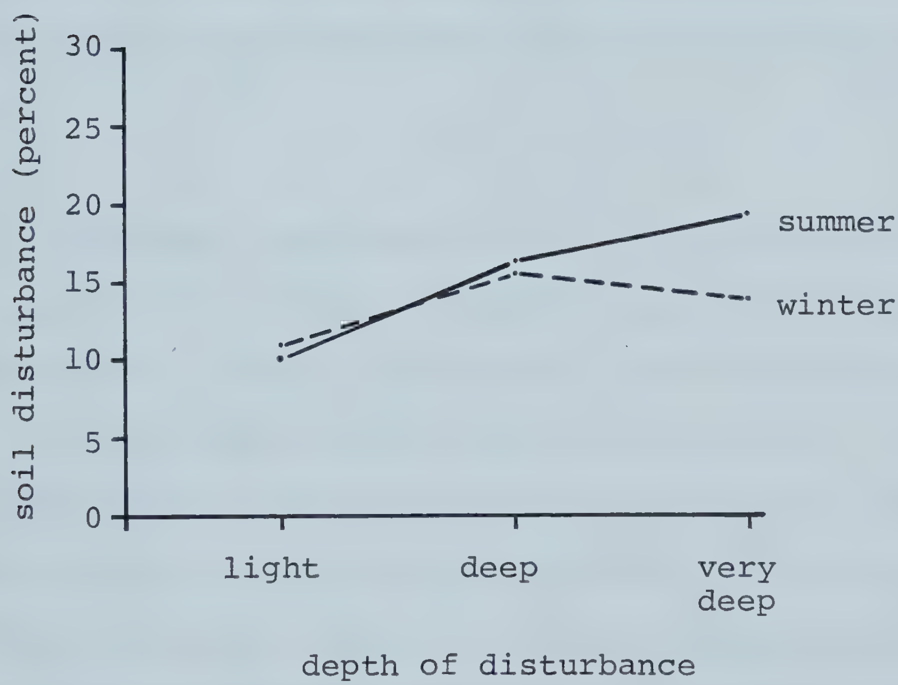

FIGURE 10. Distribution of soil disturbance by depth class for summer and winter groundskidded sites, all slopes.

[2]See Appendix IV, Table IV-2d, p. 200.

Depth/slope trends on summer and winter groundskidded blocks are compared in Figure 11. Very deep disturbance increased with increasing slope for both seasons, sharply from moderate to steep slopes on summer-logged areas and steadily from gentle to steep slopes on winter-logged blocks. Light and deep disturbance displayed no consistent trends between seasons. Both decreased steadily with increasing slope on summer-logged blocks but were variable on winter-logged blocks.

Since haul roads, landings and skid roads require larger cuts and fills on steeper slopes a trend toward deeper disturbance on steeper slopes might have been expected. This study provided limited (but not conclusive) support for this hypothesis. The observed increase of very deep disturbance with increasing slope appeared to be due to higher levels of haul road and skid road disturbance, offset by lower levels of landing disturbance, on moderate and steep slopes. However, the sample size was too small to determine whether the increases in haul road and skid road disturbance were due to slope effects or other topographic and logging-related factors. The decrease in landing disturbance on steep slopes is thought to reflect a reduction in numbers and dimensions of landings on slopes greater than 40 percent.

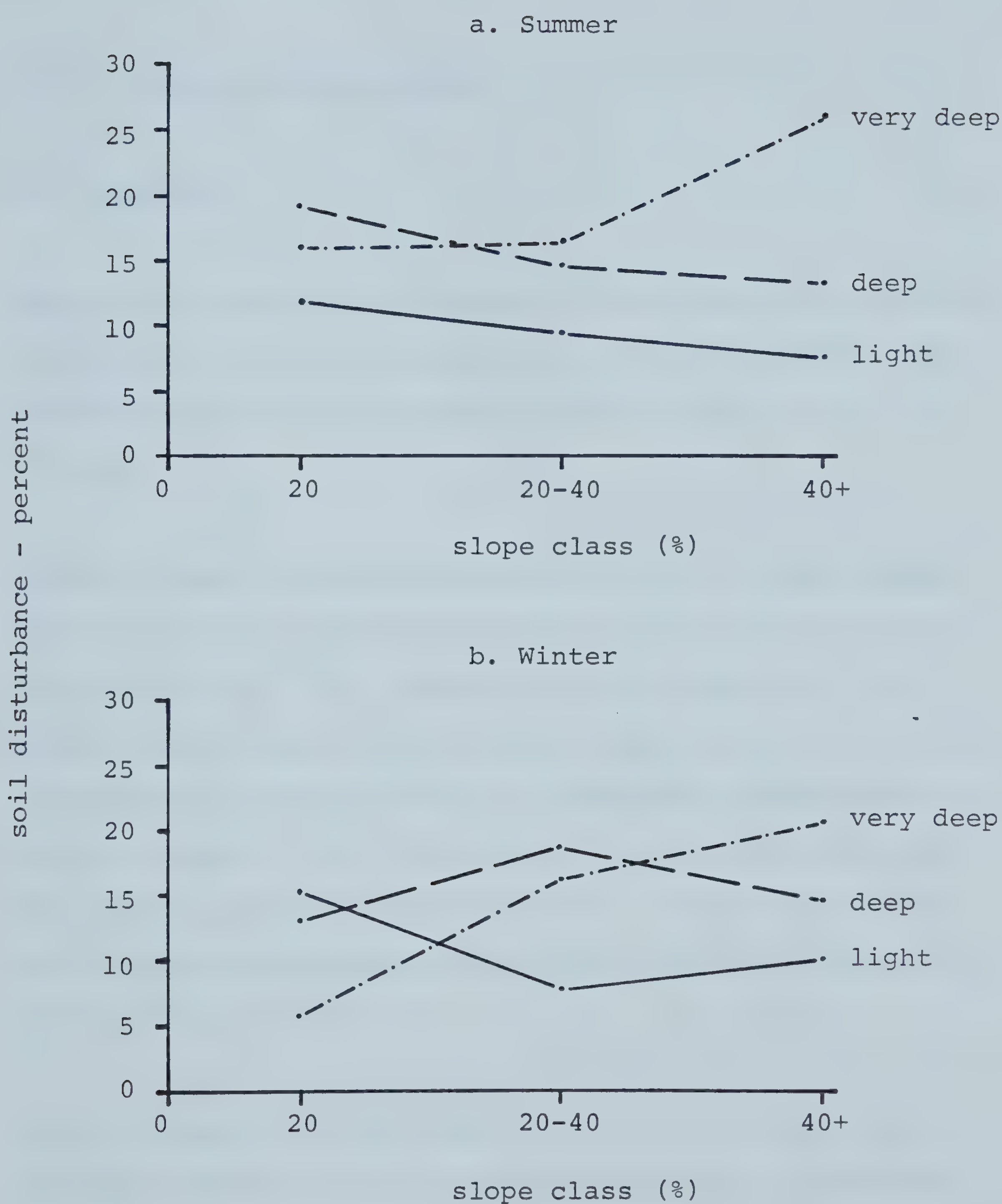

FIGURE 11. Trends in light, deep and very deep soil disturbance with increasing slope on summer and winter groundskidded sites.

4.2.6. Source of Disturbance

(a) General

Many of the observed differences between and within methods as well as seasons of logging appeared to be closely connected to differences in source contributions to soil disturbance.

Levels of haul road disturbance were similar among summer cable-logged and summer and winter groundskidded clearcuts (9.0%, 8.3% and 7.6%, respectively) (see Table 1), but winter cable-logged sites had much higher average haul road disturbance (16.6%). This was attributed to differences in cutblock layout: the three winter-logged units consisted of long narrow strips of timber parallel to or between haul roads, and having comparatively short yarding distances of not more than 120 metres.

Since most of the cable-logged units in this study were designed around haul road networks originally planned for groundskidding systems, estimates of haul road disturbance from this study may not have accurately reflected haul road densities for cable yarding systems.

Figures for landing disturbance reflect important operational differences between the two logging systems. On similar slopes, landings on cable-yarded blocks were smaller (and in some cases not required) than those on groundskidded blocks. There was a noticeable tendency on groundskidded blocks to build large landings on gentle terrain and smaller landings on steeper, rougher slopes.

It was expected that differences in soil disturbance levels between the two logging systems would be largely explained by differences in skid road-related disturbance, since skid roads are a necessary feature of groundskidding systems (on steep slopes), but not of cable-yarding systems. The surveys supported this hypothesis. Unexpectedly, however, skid roads were present on five of the six cable-yarded sites. Reasons were not always apparent. It was hypothesized that tractors may have been used to log isolated patches of poor deflection within the cable settings, or perhaps moved from adjacent groundskidded to cable-yarded areas to smooth out log production or to simplify scheduling of equipment moves.

Nineteen of twenty-five groundskidded clearcuts had 20% or more skid road disturbance. The remaining six blocks had less than 20% disturbance associated with skid roads.

Possible explanations for these low values were: (1) gentle to flat slopes; (2) logging over deep snowpacks; (3) deep duff layers; and (4) widely-spaced skid roads.

Disturbance caused by yarding was distributed evenly over groundskidded clearcuts but tended to be concentrated near landings or roadsides on the cable-yarded units. Possible reasons for the high levels of yarding-related disturbance on summer cable-logged areas were discussed earlier (Section 4.2.3.). On summer groundskidding operations, low levels of yarding disturbance were associated with high-elevation, moist sites with deep duff layers, while on winter-logged sites low values appeared to reflect either deep duff layers or deep snowpacks, or both. The high yarding disturbance values of three winter-logged blocks having gentle average slopes (Blocks 0202, 0401 and 0405) was probably caused by misclassifying some disturbance on poorly-defined skid trails.

(b) Variation With Logging Method

Skid roads caused significantly more disturbance than any other source on groundskidded sites, while haul roads, the

second largest source, contributed significantly more than landings or yarding.[3] The order of importance and levels of significance were identical for both summer and winter operations. Based on summer and winter data combined, haul roads were the largest contributor of disturbance on cable-yarded clearcuts.[4] Yarding was the second largest source, causing significantly more disturbance than landings but not more than skid roads.

In contrast to the groundskidded clearcuts, rankings of disturbance sources on cable-yarded sites were very different for summer and winter operations. The single largest source of disturbance on summer-logged clearcuts was yarding, followed in order by haul roads, skid roads and landings (see Table 1), whereas on winter-logged clearcuts haul roads caused the most disturbance, with skid roads second, yarding third and landings fourth. (For reasons discussed earlier, however, these differences should not be regarded as entirely seasonal in nature.)

As was expected, skid roads generated significantly more

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[3]See Appendix IV, Table IV-2a, p. 199.
[4]See Appendix IV, Table IV-1c, p. 196.

soil disturbance on groundskidded than on cable-yarded clearcuts.[5] Estimates of haul road, landing and yarding disturbance did not differ significantly between the two logging methods. Therefore there is little doubt that for this study, skid roads were responsible for the higher levels of soil disturbance associated with groundskidding as compared with cable logging methods.

(c) Variations in Depth Distributions

The relationships between sources of soil disturbance and their depth distribution profiles are perhaps the most striking features of this survey. Each disturbance source shows a clear and consistent depth profile that is independent of method and season of logging and is distinct in shape and/or magnitude from the profiles of other sources. Statistically, the interactions between source and depth of disturbance are among the strongest relationships found in the survey data.

Table 6 summarizes depth-of-disturbance distributions by method and season of logging for each disturbance source.

[5]See Appendix IV, Table IV-1c, p. 196 .

Table 6. Distribution of soil disturbance by source and depth class.

LOGGING METHOD	LOGGING SEASON	SOURCE OF DISTURBANCE	DEPTH CLASS LIGHT	DEPTH CLASS DEEP	DEPTH CLASS VERY DEEP	TOTAL DISTURBANCE BY SOURCE
Ground-skidding	Summer	Haul Roads	0.5%	1.3%	6.5%	8.3%
		Skid Roads	6.9	12.6	9.3	28.8
		Landings	0.3	1.5	3.3	5.1
		Logging	2.3	0.7	0.2	3.2
Totals by Depth Class			10.0%	16.2%	19.2%	45.4%
Ground-skidding	Winter	Haul Roads	0.6%	1.9%	5.1%	7.6%
		Skid Roads	6.5	12.0	6.0	24.4
		Landings	0.5	1.5	2.4	4.3
		Logging	3.1	0.7	0.1	4.0
Totals by Depth Class			10.7%	16.1%	13.6%	40.4%
Cable-Yarding	Summer	Haul Roads	0.9%	1.4%	6.7%	9.0%
		Skid Roads	0.2	1.4	1.2	2.8
		Landings	0.3	0.1	0.9	1.3
		Logging	13.7	2.6	0.1	16.4
Totals by Depth Class			15.1%	5.5%	8.9%	29.5%
Cable-Yarding	Winter	Haul Roads	1.4%	1.9%	13.3%	16.6%
		Skid Roads	0.6	1.5	0.7	2.8
		Landings	0.0	0.2	0.3	0.5
		Logging	2.3	0.2	0.0	2.5
Totals by Depth Class			4.3%	3.7%	14.3%	22.3%

The depth profiles of haul road-related disturbance are characterized predominantly by very deep disturbance (see Figure 12). Between 67 and 80% of all haul road disturbance is classed as very deep. About two-thirds of the remainder is deep disturbance and one-third is light.

The pattern is consistent for all logging method/season groupings, which is reasonable in light of normal road construction practices. Standards, methods and timing of haul road construction are generally independent of the method or timing of logging. Haul roads are usually built in dry weather (summer). Sizeable cuts and fills are usually needed even on gentle slopes to build a wide firm road base. As a result very deep disturbance dominates across most of the road with light and deep disturbance limited to the outer margins of the road prism.

The actual amount of haul road disturbance associated with a given logging system varies depending on the road density requirements, which in turn varies inversely with yarding distance. Thus, winter cable-logged sites, with short average yarding distances, have higher road densities and more haul road-related disturbance than the other logging method/ season combinations. Also the high proportion of

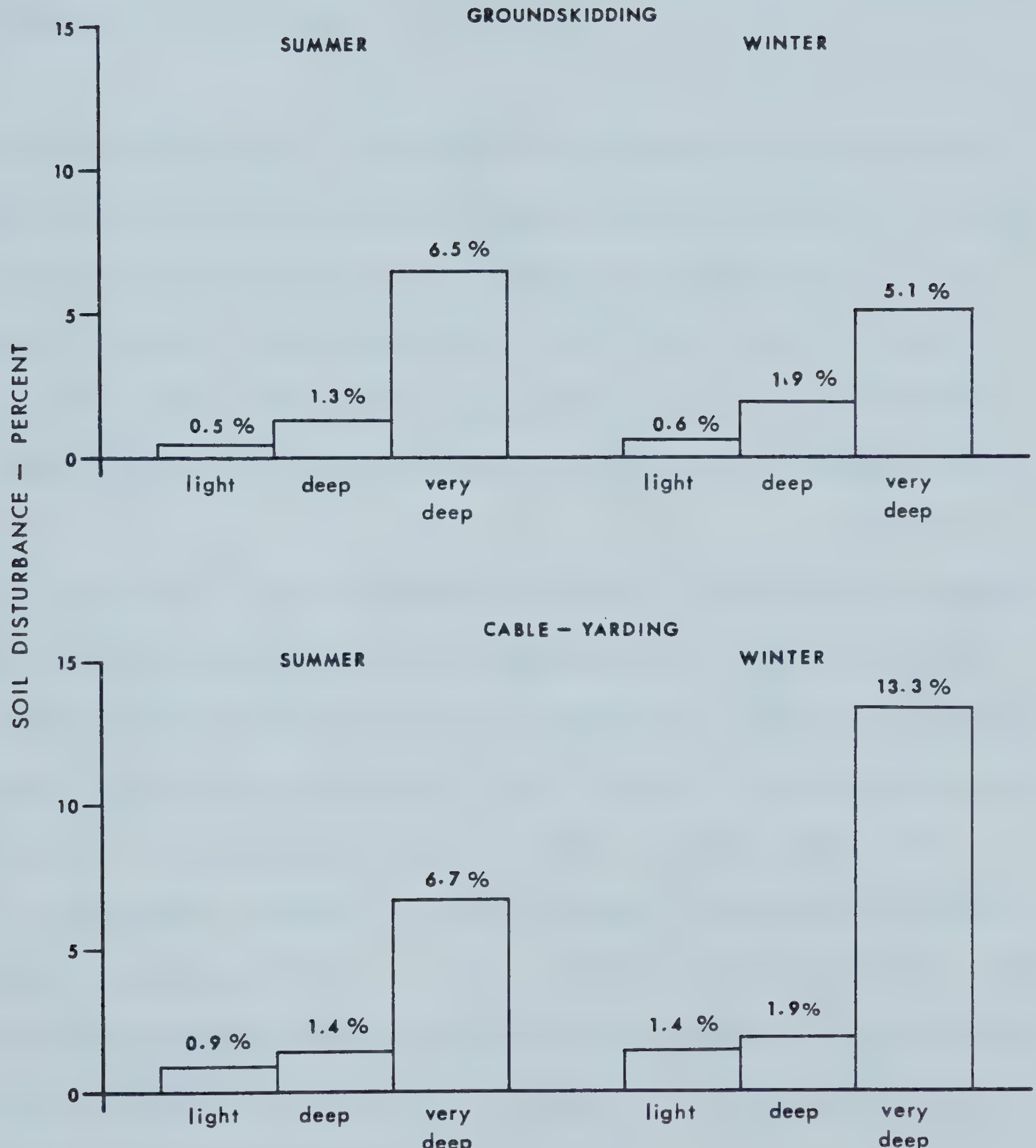

FIGURE 12. Distribution of soil disturbance by depth class for haul roads.

very deep disturbance on the winter cable-logged sites is linked directly to the high level of haul road disturbance recorded for these sites.

With minor variations, the depth distribution pattern of landing-related disturbance (Figure 13) is identical to that of haul roads but differs principally in magnitude. Construction methods and machinery, and often timing, are similar for both haul roads and landings, so it is reasonable that the depth distribution patterns are similar also.

However, landings are designed to serve a particular logging system. Their specifications (number, size and placement) are influenced by the choices of logging system and logging equipment which in turn affect the levels of landing-related disturbance. Figure 13 suggests that landing densities and/or sizes are similar for both summer and winter ground-skidding operations and less for cable yarding systems. The lower landing disturbance on the cable-yarded sites probably reflects a tendency to build landings to minimum practical dimensions on steep slopes.

Depth distribution patterns for skid roads (shown in Figure 14) approximate normal distributions for all four logging

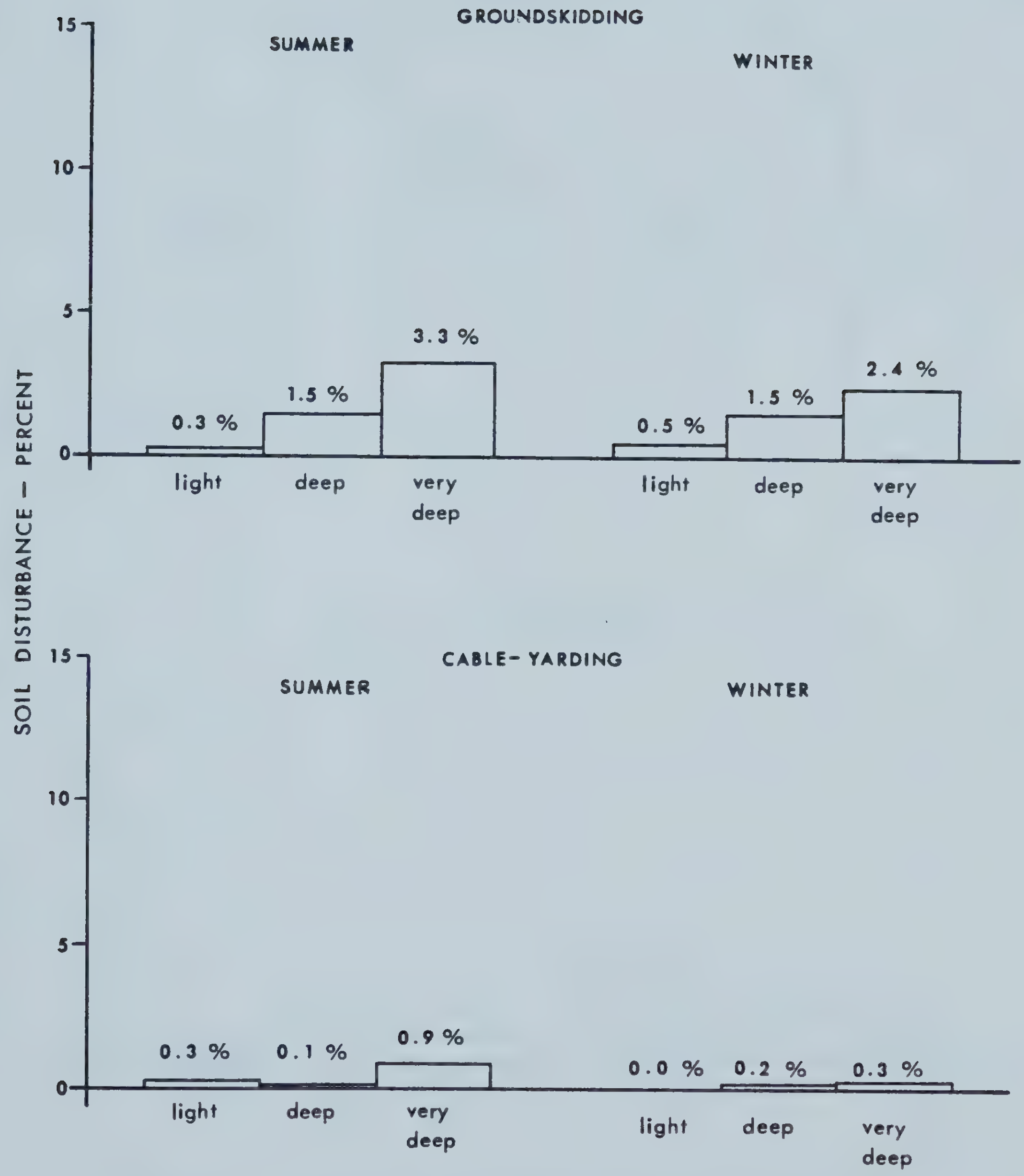

FIGURE 13. Distribution of soil disturbance by depth class for landings.

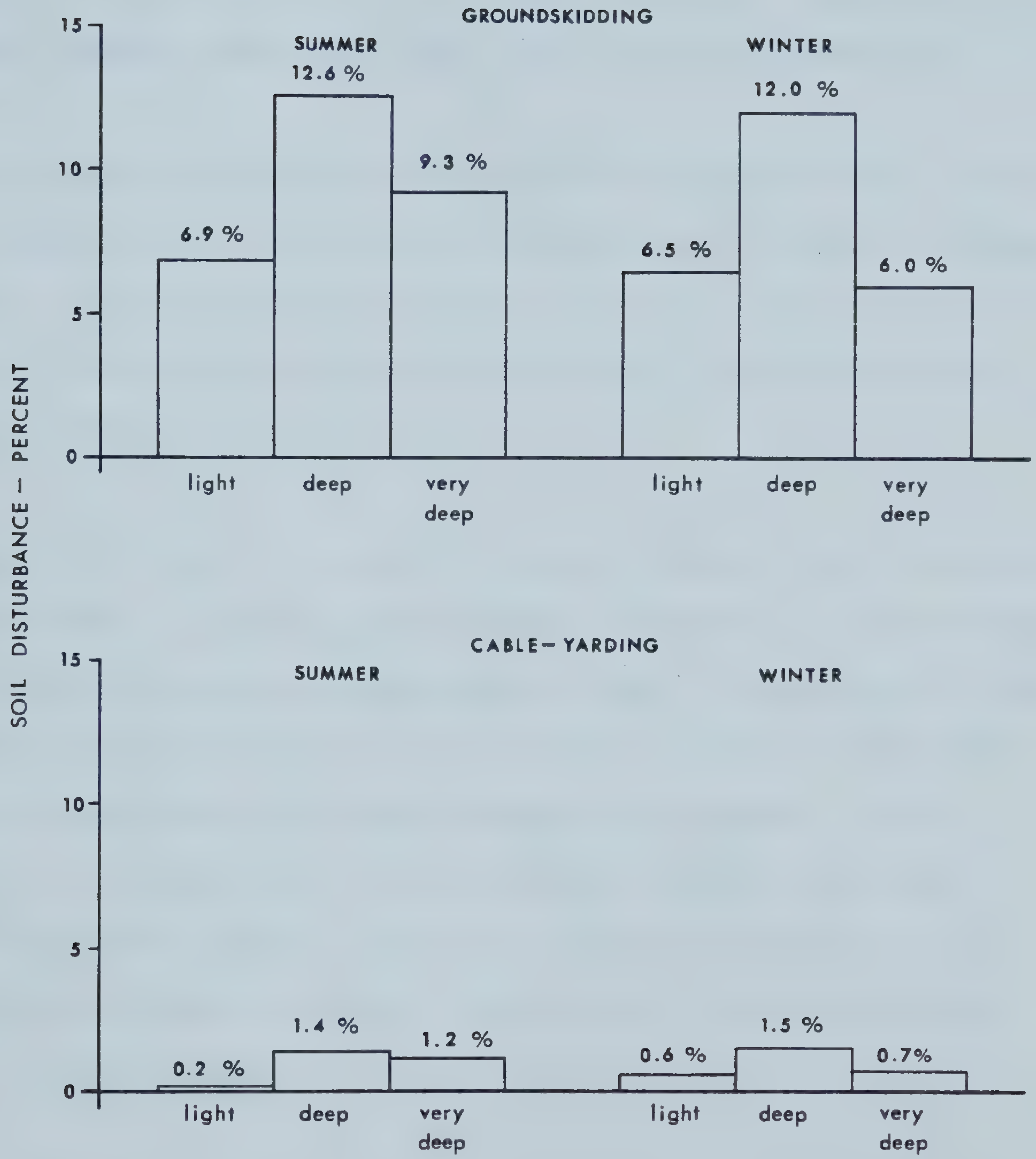

FIGURE 14. Distribution of soil disturbance by depth class for skid roads.

method/season groupings. Deep disturbance generally accounts for about half of the total, with the remainder split fairly evenly among the light and very deep categories.

Skid roads are built in much the same manner as haul roads on slopes of more than about 30 percent. The smaller dimensions (narrower widths, smaller cuts and fills) result in a shift of the depth distribution pattern from mostly very deep to deep disturbance.

Since skid roads are usually (but not always) built during rather than in advance of logging, it might be expected that logging over deep snowpacks would cause a reduction in skid road-related disturbance or at least a shift in depth distributions toward shallower overall disturbance. While there are indications of this between summer and winter groundskidded blocks (less very deep and less total skid road disturbance on winter-logged blocks) the differences are not conclusive.

The depth distribution pattern of yarding-related disturbance, shown in Figure 15, is essentially opposite to those of haul roads and landings: light disturbance dominates the profile, deep disturbance constitutes the next largest

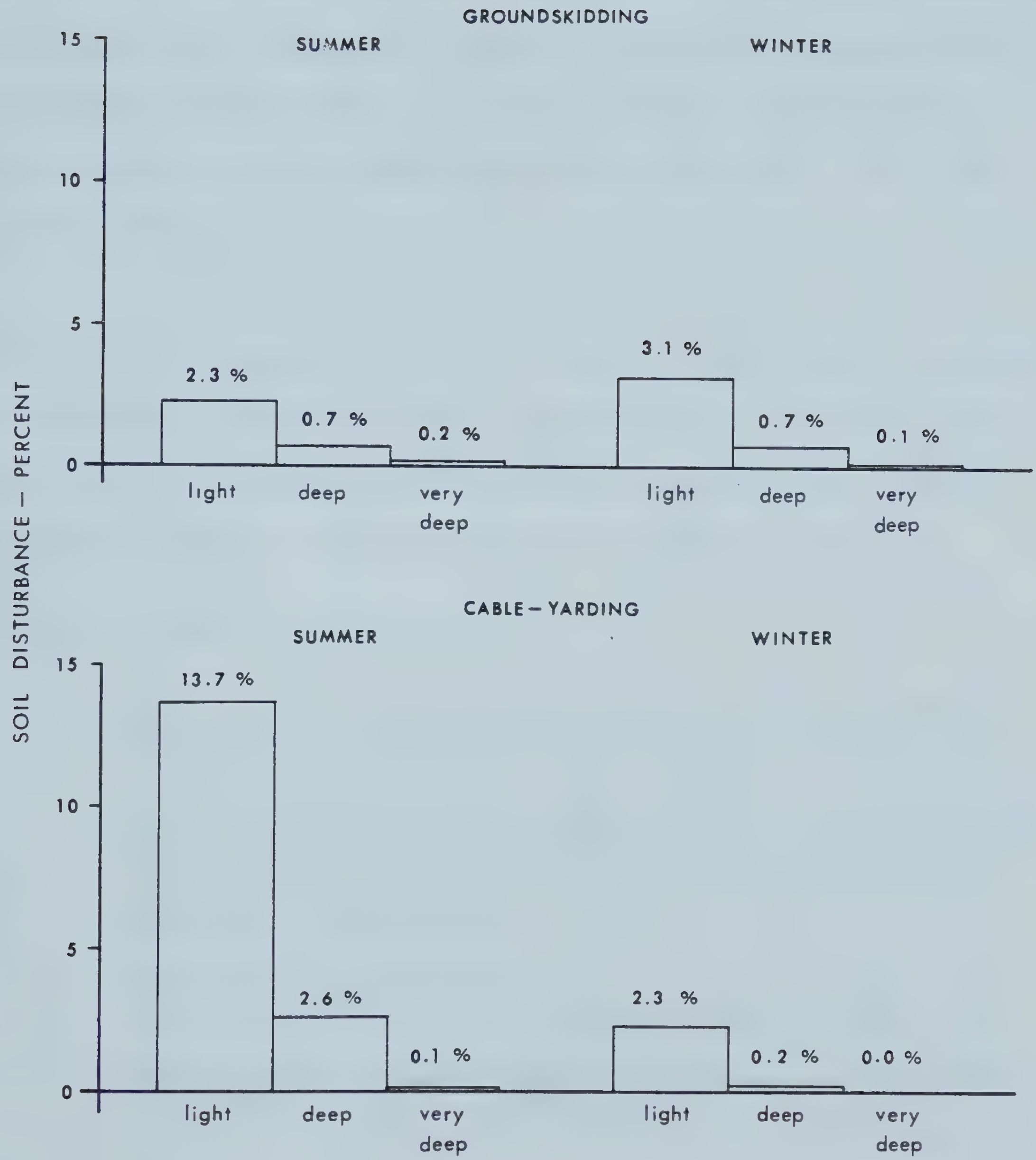

FIGURE 15. Distribution of soil disturbance by depth class for yarding.

proportion and very deep disturbance accounts for only a small fraction of the total. Also, the patterns and amounts are similar for summer and winter groundskidding and winter cable-yarding operations. Reasons for the high yarding disturbance levels on summer cable-yarded sites have been reviewed earlier.

A Newman-Kuels Range Test of the twelve means (four sources X three depth classes) showed the following statistically significant differences within (i.e., within their respective depth profiles) and between disturbance sources[6]:

(i) Within-Source Differences

1. Haul roads are characterized more by very deep than deep or light disturbance (see Figure 12).

2. Landings are characterized more by very deep than light disturbance (see Figure 13). Levels of deep disturbance are intermediate between light and very deep disturbance and are not statistically different from either.

3. Skid road construction generates more deep than light or very deep disturbance (see Figure 14).

4. Yarding causes more light than deep or very deep disturbance (see Figure 15).

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[6]See Appendix IV, Table IV-2c, p. 200.

(ii) Between-Source Differences

Groundskidded clearcuts have the following features:

1. Skid roads and haul roads, in that order, are the largest contributors of very deep disturbance on groundskidded clearcuts. Landings contribute less very deep disturbance than skid roads and haul roads, but more than yarding.

2. Skid roads generate more deep disturbance than any other source. Haul roads, landings and yarding, in that order, contribute lesser quantities.

3. Skid roads also generate more light disturbance than any other source. Yarding is the second largest source. Haul roads and landings are minor sources of light disturbance, contributing significantly smaller quantities than skid roads or yarding.

Cable-yarded clearcuts are characterized by the following:

1. Haul roads are the primary source of very deep disturbance on cable-yarded sites, accounting for 75% and 93% of all very deep disturbance on summer- and winter-logged sites, respectively. Skid roads and landings contribute almost all of the remainder. Yarding provides only 1% of the very deep disturbance on summer-logged sites and none on winter-logged sites.

2. Yarding contributes about half of the deep disturbance on summer-logged sites, the remainder being split evenly between haul roads and skid roads. On winter-logged sites haul roads and skid roads account for 50% and 40% of all deep disturbance, respectively.

3. Yarding also contributes almost all light disturbance on summer-logged sites and slightly more than half on winter-logged sites. Haul roads are the second largest source, while skid roads and landings are minor sources.

(d) Effect of Slope on Source Distributions

Two slope effects were isolated among the distributions of soil disturbance according to source[7]:

1. Skid road-related soil disturbance was significantly greater on slopes greater than 20% than on slopes less than 20 percent;

2. Landing-related soil disturbance was significantly lower on slopes greater than 40% than on slopes less than 40 percent.

Skid road-related disturbance on gentle groundskidded clearcuts averaged 20.9% compared to 29.2% on the clearcuts having moderate and steep slopes. This difference may be partly due to the fact that tractors must build skid roads in order to work safely and efficiently on steeper slopes, whereas on gentle slopes skid roads are not always necessary. The apparent statistical significance of the increase in skid road disturbance on moderate and steep slopes seems questionable, however, in view of the very high range in skid road-related soil disturbance on gentle slopes (2.3% to 38.1%) (see Table 4). If two clearcuts with very low levels of skid road-related disturbance (Blocks 0405 and 0406, Hall Lakes) were excluded, average skid road disturbance on gentle slopes would increase to 25.6 percent.

[7]See Appendix IV, Table IV-2c, p. 200.

The statistically significant reduction of landing-related soil disturbance on steep slopes supported observations made during the field surveys that fewer and smaller landings were built on steep than on gentle or moderate slopes. Landings were built as needed and to relatively large dimensions where terrain afforded easy construction. On steep slopes, however, landing location and size appeared to be dictated more by the frequency and size of suitable benches and ridges.

Analysis of Variance also discerned significant interactions (at the 95% level) between slope class, source, and depth of disturbance on groundskidded blocks (see Table 3). Owing to the large number of means involved (36) the Newman-Kuels Range Test could not be applied to isolate the significant effects. However, graphical comparisons of disturbance trends with slope showed the strongest trends in disturbance levels occurred in the very deep class and the weakest occurred in the light class, while skid roads and haul roads appeared to be possible sources of significant slope effects (see Figure 16).

Slope-related trends in very deep disturbance were also strongly associated with source of disturbance. Quantities of very deep disturbance increased with increasing slope for

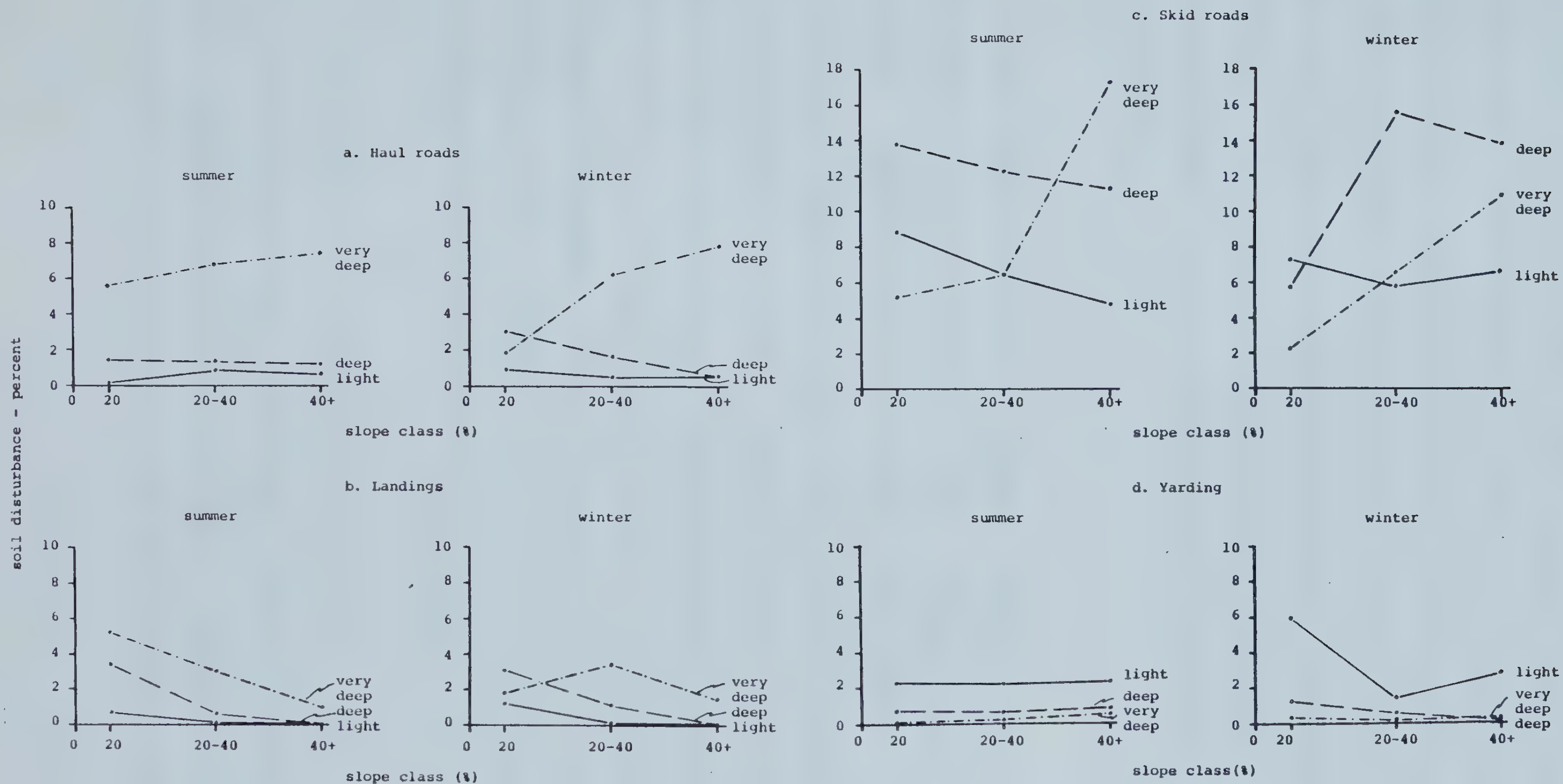


FIGURE 16. Trends in light, deep and very deep soil disturbance, by source, with increasing slope on summer and winter groundskidded sites:

a. Haul roads.
b. Landing.
c. Skid roads.
d. Yarding.

haul roads and skid roads but remained static for yarding and decreased for landings. Levels of deep disturbance appeared to be comparatively less affected by either slope or source, and generally displayed static to moderately declining trends with increasing slope. Levels of light disturbance also remained constant or declined slightly with increasing slope but the trends were even weaker than for the deep class.

Skid roads exhibited the strongest slope effects on disturbance levels in quantitative terms (Figure 16c). The proportion of disturbance in the very deep class increased substantially from gentle to steep slopes on both summer- and winter-logged blocks. Light and deep disturbance both decreased with increasing slope on summer-logged sites but were variable on winter-logged sites. The trend toward an increasing proportion of very deep disturbance as slopes became steeper was thought to be due to the deeper cuts and fills needed to build skid roads on steep slopes.

Haul roads (Figure 16a) displayed slope-related trends similar to those of skid roads but distinct in two respects: (1) haul roads caused less total soil disturbance than skid roads; and (2) disturbance in the very deep class constituted

a much larger proportion of total disturbance for haul roads than for skid roads. Nevertheless, the proportion of very deep disturbance increased with increasing slope, moderately on summer-logged sites and sharply on winter-logged sites. Levels of light and deep disturbance remained constant or declined slightly with increasing slope for both logging seasons. As with skid roads, the increase in very deep disturbance was thought to reflect the need for larger cuts and fills on steeper slopes.

Landings (Figure 16b) showed a steady decline in disturbance levels for all depth classes with increasing slope. This was considered to be due more to a tendency to build smaller and fewer landings on steeper slopes than to changes in construction techniques. Yarding disturbance (Figure 16d) showed no obvious slope-related trends on either summer- or winter-logged blocks. High levels of light disturbance on winter-logged blocks having gentle slopes probably resulted from incorrectly attributing some disturbance to yarding instead of skid roads.

Not enough information was available to perform a similar analysis for slope effects on soil disturbance levels for cable-yarded sites.

4.3. Results of Analyses and Comparisons of Soil Properties on Skid Road Surfaces

The soil disturbance surveys supported the view that groundskidding logging methods caused more total soil disturbance than cable logging methods. Skid roads were clearly identified as the primary source of the additional disturbance. Furthermore, skid roads were also found to contribute 48 and 44% of the very deep disturbance recorded on summer- and winter-logged sites, respectively. In view of these findings it was decided to supplement the soil disturbance surveys with comparisons of several soil properties on skid road surfaces and adjacent undisturbed soils. The purpose of these comparisons was to indicate the potential magnitude and direction of alterations to soil properties that could be expected to result from skid road construction and use.

One summer groundskidded clearcut in each of two drainages (Quartz Creek and Rock Creek) was selected for this survey. Soil properties for skid road surfaces and adjacent undisturbed soil sites were determined and compared at five locations on each study site. In general soils on skid road surfaces at both study sites were intermediate in chemical and physical characteristics between those of the surface and C-horizon of adjacent undisturbed soils, but in almost

all cases more closely resembled C-horizon than A-horizon conditions.

Table 7 presents averages and ranges of chemical and physical properties of undisturbed Quartz Creek and Rock Creek soils as determined by this survey. Almost all of the samples taken from skid road surfaces also fell within these ranges.

4.3.1. Soil pH

The strongly alkaline Rock Creek soils had higher pH values than their Quartz Creek counterparts at all sampling locations (see Figure 17). On both sites the pH of the C-horizon was considerably higher than that of surface (A-horizon) soils. As Figure 17 also shows, pH of skid road surfaces averaged significantly higher than pH of undisturbed A-horizons, and in general was very similar to subsoil values.

Table 7. Comparison of soils on Quartz Creek and Rock Creek study sites.

SOIL PROPERTY	QUARTZ CREEK	ROCK CREEK
1. Soil pH		
- surface	4.5 (4.2-4.6)	6.4 (5.6-7.1)
- C-horizon	5.7 (5.5-5.9)	8.1 (8.0-8.3)
2. Soil Carbon (%)		
(a) Surface		
- organic	1.7 (0.9-2.6)	0.5 (0.4-0.6)
- carbonate	0.0	0.0
- total carbon	1.7 (0.9-2.6)	0.5 (0.4-0.6)
(b) C-Horizon		
- organic	0.5 (0.1-0.9)	0.2 (0.0-0.6)
- carbonate	0.0	13.8 (7.2-23.0)
- total carbon	0.5 (0.1-0.9)	1.9 (1.1-2.8)
3. Soil Texture		
- surface - C-horizon	gsl	(s)sil
4. Bulk Density (g/cm^3)		
- surface	1.09 (0.87-1.35)	1.35 (1.18-1.56)
- C-horizon	1.57 (1.25-1.85)	1.67 (1.47-1.89)
5. Soil Classification[1]	Podzolic (?) Gray Luvisols	Orthic Eutric Brunisols

[1] Canada Soil Survey Committee, 1978.

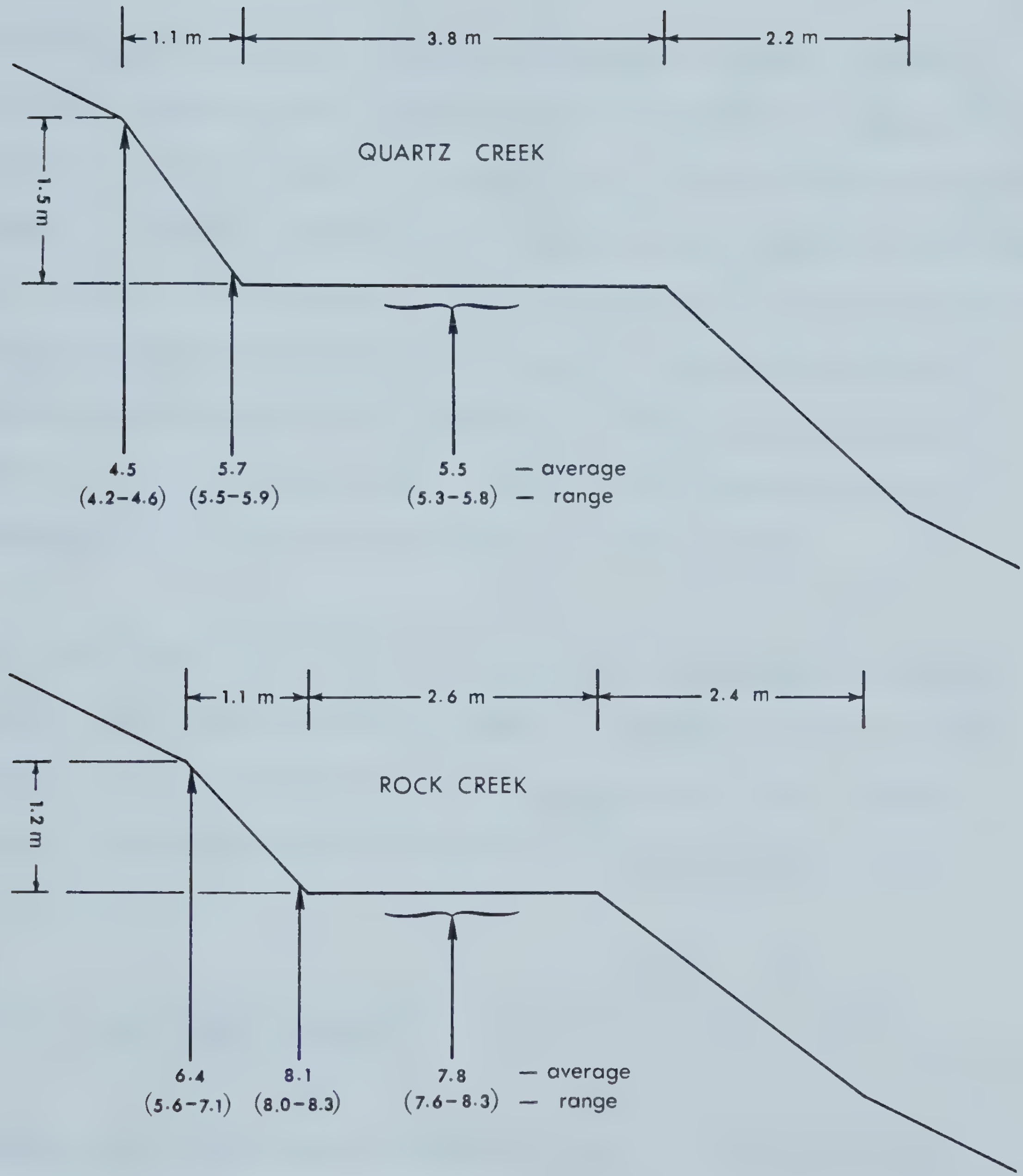


FIGURE 17. Comparison of soil pH measurements for Quartz Creek and Rock Creek soils.

4.3.2. Soil Carbon Content

Variations within and between sites for organic carbon, calcium carbonate and total carbon are shown in Figure 18. In Quartz Creek soils all carbon was in the form of organic carbon. Calcium carbonate was absent from the soil profile to a depth of 1.5 metres. Rock Creek soils, by comparison, contained significantly less organic carbon than Quartz Creek soils but had high levels of carbonate below the A-horizon. As a result total soil carbon content was not significantly different between the two sites.

Skid road surfaces of both sites were intermediate between A- and C-horizon values in terms of organic carbon content. However, the carbonate (and, consequently, total carbon) content of Rock Creek skid roads was very similar to C-horizon levels.

4.3.3. Soil Bulk Density

Maximum bulk densities occurred in the C-horizon and decreased steadily out to the fill (sidecast) slope where it was at a minimum (see Figure 19). Bulk densities were higher at each sample location for Rock Creek than for

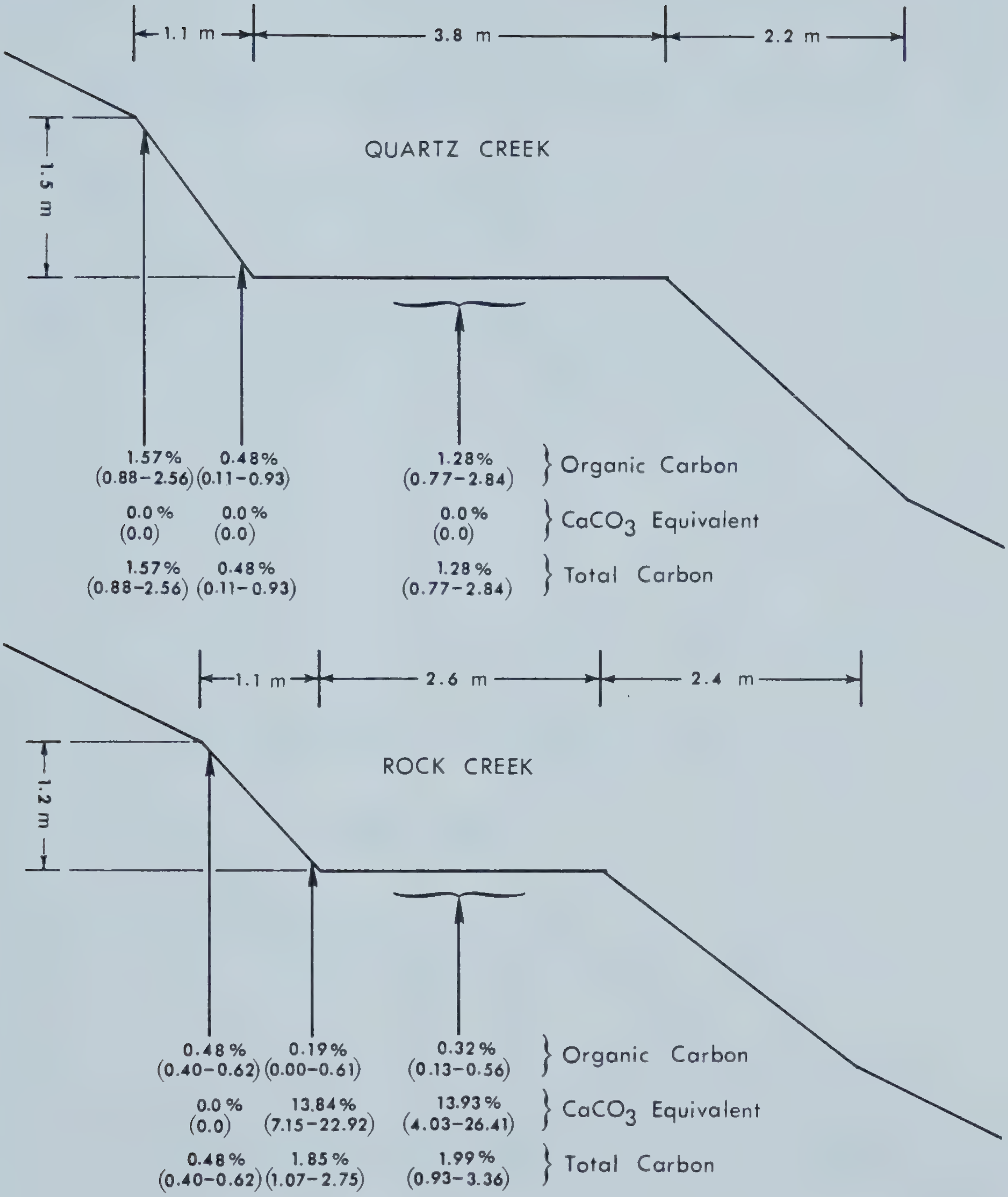


FIGURE 18. Comparison of soil carbon contents for Quartz Creek and Rock Creek soils.

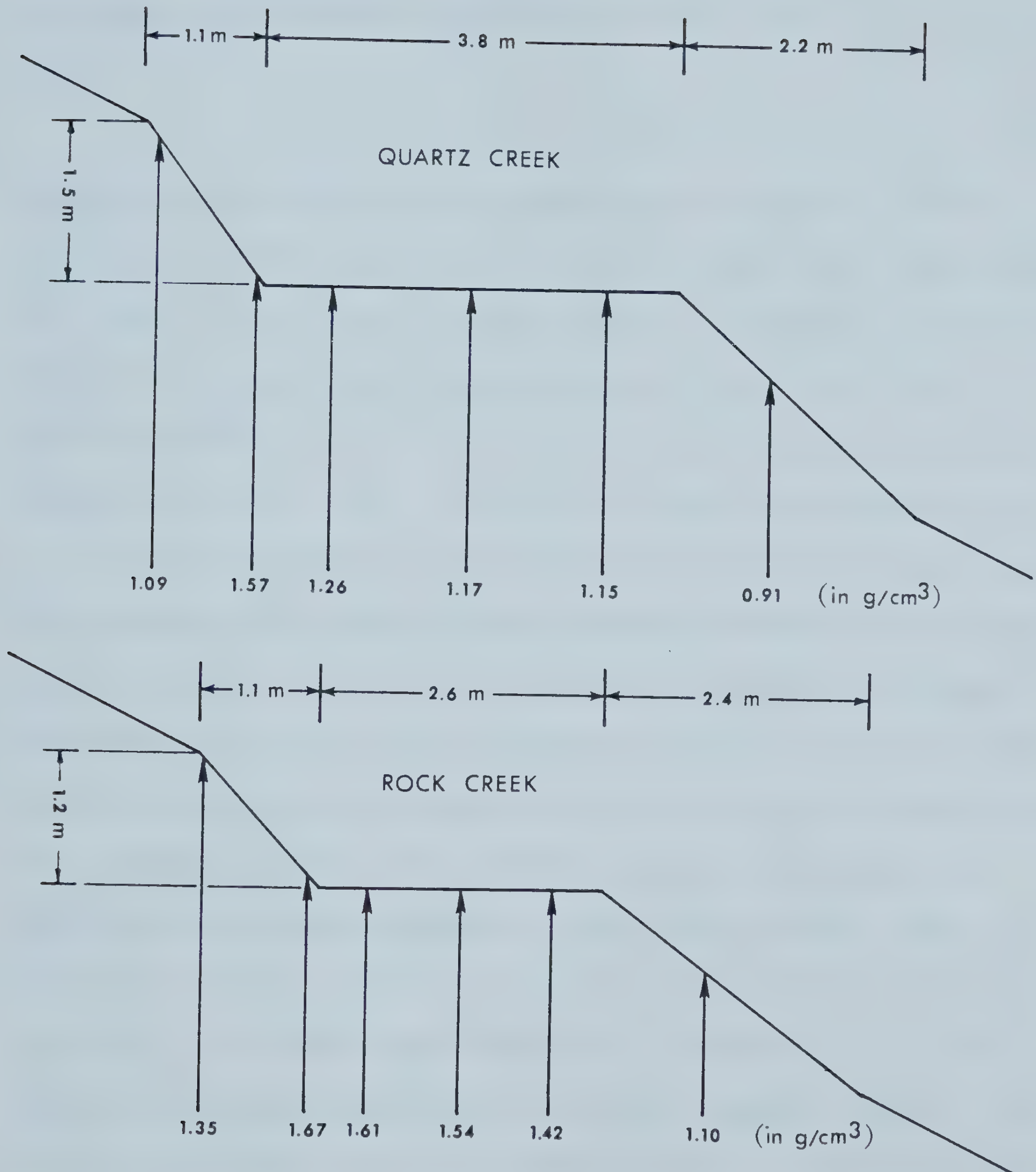


FIGURE 19. Comparison of soil bulk densities for Quartz Creek and Rock Creek soils.

Quartz Creek soils. The average bulk density of Rock Creek soils was also significantly higher than for Quartz Creek soils.

On both study sites the average bulk density of the A-horizon of undisturbed soils is lower (but not significantly so) than for the inner track, center, and outer track positions on the skid road surfaces (1.09 g/cm^3 for the A-horizon versus 1.15 to 1.26 g/cm^3 for the skid road surfaces on Quartz Creek, and 1.35 g/cm^3 for the A-horizon versus 1.42 to 1.61 g/cm^3 for the skid road surface on Rock Creek). The maximum differences occur between A-horizon and inner-track values; the minimum, between A-horizon and outer-track values. Only the bulk density of the C-horizon was significantly greater than that of the A-horizon (see Table 8). Logging traffic has probably caused some soil compaction on skid road surfaces (see, for example, the bulk densities of the outer track area, which is built on fill material). On the inner-track area, however, it is not possible to distinguish the effect of logging traffic from the natural trend toward increasing bulk density as soil depth increases.

Table 8. Results of Newman-Kuels Range Test for soil bulk density versus location in a skid road cross-section.

	UNDISTURBED BASE	INNER TRACK	CENTER TRACK	OUTER TRACK	UNDISTURBED SURFACE	SIDE-CAST
(g/cm^3)	1.62	1.44	1.35	1.29	1.22	1.01
Significance[1]	a	ab	abc	abc	bc	c

[1]Means having the same letter in common are not significantly different at the 5% level.

The lack of statistical differentiation between average bulk densities of undisturbed surface soils and skid road soils is probably due to insufficient sample size. Only one bulk density sample per zone was collected at each sample skid road, yielding a total of five bulk density samples per zone for each of the Quartz Creek and Rock Creek study sites.

4.3.4. Soil Texture (Particle-Size Distributions)

Quartz Creek soils were coarser than Rock Creek soils, having larger proportions of gravels and smaller proportions of silts and clays. The former were classified as gravelly

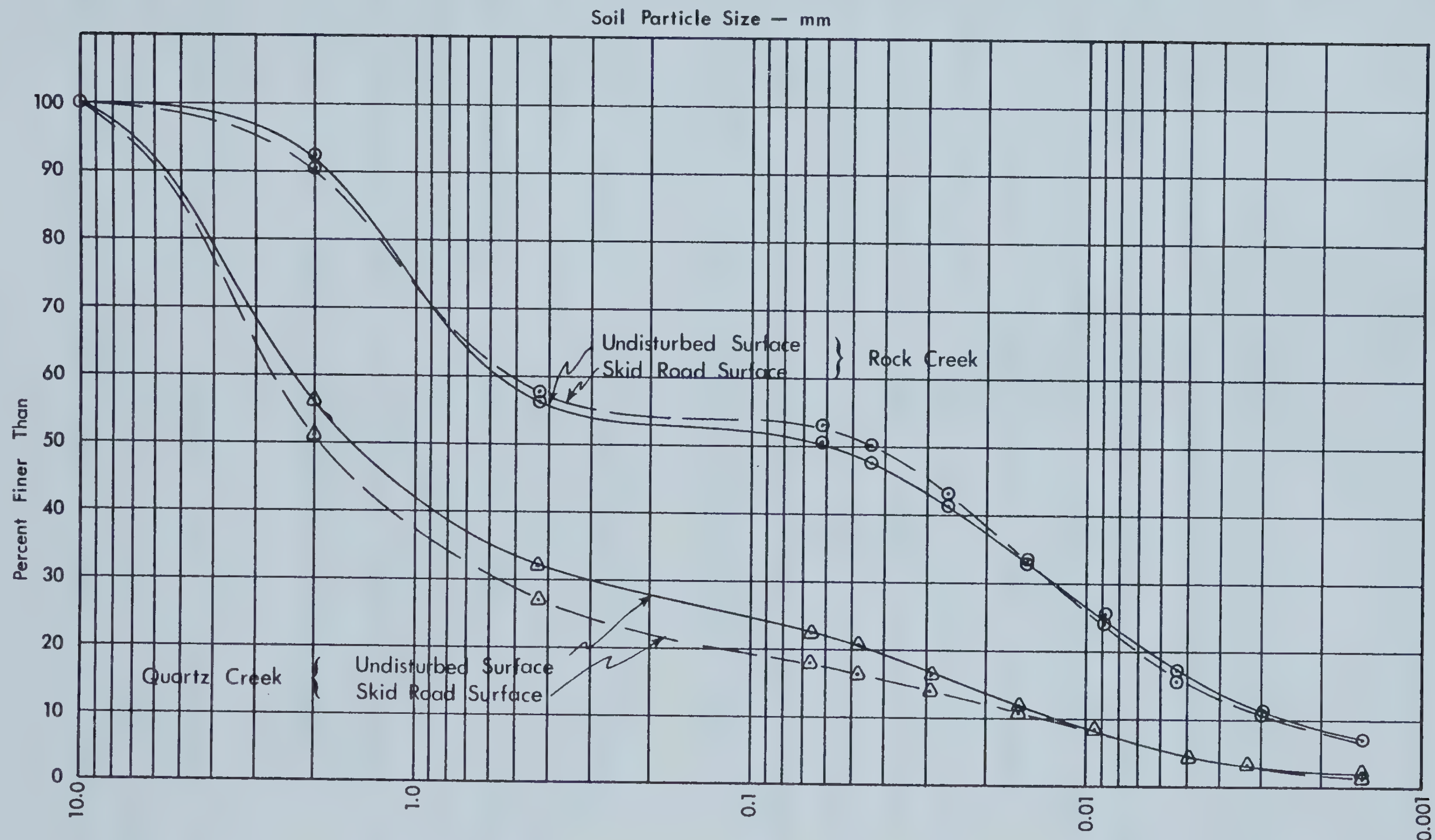
sandy loams and the latter as silt loams (Canada Soil Survey Committee, 1978).

Figure 20 compares average particle-size distributions for the A-horizons and skid road surfaces of both sites. (Samples taken from the C-horizons were essentially identical and therefore were not included.) It is apparent that soil textures on skid road surfaces are not significantly different from the surface soils.

4.3.5. Fifteen-Minute Infiltration Rates

Falling-head infiltration rates for skid road surfaces (inner-track zone) and adjacent mineral soil surfaces (above the skid road cutbank, litter layer removed) were measured using a double-ring infiltrometer arrangement (Lewis, 1968). One pair of infiltration tests (one on-road and one off-road) was run on each sampled skid road, yielding five pairs of tests for each study site. (Soil samples for determination of other soil properties, including bulk density, were also collected in the immediate vicinity of the infiltration test sites.) Due to lack of water nearby, test durations were in general limited for purposes of

FIGURE 20. Soil particle-size distributions for undisturbed surface and skid road surface soils, Quartz Creek and Rock Creek sites.



comparison by the infiltration rates of the undisturbed soils.

Infiltration rates for all but the undisturbed Quartz Creek soils were characterized by high variability (see Table 9). Anomalous readings included: (1) for Rock Creek, a high rate of 55.3 cm per fifteen minutes on an undisturbed soil and a high rate of 14.9 cm per fifteen minutes on a skid road surface; and (2) for Quartz Creek, a low reading of 7.2 cm per fifteen minutes on a skid road surface. Four of the five road surface measurements at the Rock Creek site were between 0.2 and 0.5 cm, while on Quartz Creek road surfaces four of five readings were between 15.8 and 25.5 cm.

At Quartz Creek, average infiltration rates of skid road surface were about 70% of the average value for undisturbed soils, with a range of 29 to 96 percent. Skid road surfaces at Rock Creek had an average infiltration rate of only 15% of the rate for undisturbed soils, with samples ranging from less than one to 62% of their undisturbed counterpart.

On- and off-road infiltration rates at Quartz Creek were not significantly different but at Rock Creek infiltration rates of skid road surfaces were significantly lower (at a 95% of

Table 9. Comparison of fifteen-minute head losses for on-road and off-road positions, Quartz Creek and Rock Creek.

	UNDISTURBED SOIL SURFACE	SKID ROAD SURFACE
QUARTZ CREEK		
RANGE	22.8 - 28.9 cm	7.2 - 25.5 cm
AVERAGE	26.1 cm	18.3 cm
ROCK CREEK		
RANGE	7.4 - 55.3 cm	0.2 - 14.9 cm
AVERAGE	22.6 cm	3.3 cm

confidence) than those for undisturbed soils. The magnitudes of the reductions in infiltration rates on skid road surfaces are large in comparison to the relatively small increases in bulk densities for the inner-track zones (see Figure 19), particularly for Rock Creek soils. The different response between the two sites may reflect the influence of soil texture as well as soil compaction effects.

4.3.6. Rill Erosion

Rill characteristics between the study sites differ in all respects except ranges and averages in slope gradients (see Table 10). Many of the Quartz Creek skid roads had long

Table 10. Summary of rill erosion measurements for Quartz Creek and Rock Creek.

	QUARTZ CREEK	ROCK CREEK
NUMBER OF RILLS MEASURED (NUMBER OF RILL SEGMENTS)	13 (51)	22 (46)
COMBINED LENGTH OF RILLS MEASURED	700.5 m	408.5 m
AVERAGE RILL LENGTH	53.9 m	18.6 m
RANGE IN RILL LENGTH	8.0-138.3 m	3.0-98.0 m
WEIGHTED[1] AVERAGE RILL GRADIENT	31.6%	31.4%
RANGE IN RILL GRADIENTS	8.9-40.8%	12.0-38.2%
AVERAGE VOLUME OF SOIL ERODED PER METRE OF RILL LENGTH	2 670 cm^3/m	5 044 cm^3/m
AVERAGE RILL LENGTH AND GRADIENT TO 2.5-cm DEPTH	31.2 m @ 29.6%	5.7 m @ 27.2%

[1]By horizontal distance.

continuous berms on their outer edges which channelled water for considerable distances and contributed to the large difference in average rill lengths. Yet the rills on Rock Creek skid roads cut down much more rapidly than those on Quartz Creek, reaching a depth of 2.5 cm (the one-inch depth criterion considered by Packer (1967) to be the point at

which serious erosion begins to occur) in roughly one-sixth of the distance needed for rills to achieve the same depth at Quartz Creek. The more rapid downcutting is further shown by the volume of soil eroded per unit length of rill, which is almost twice as high on Rock Creek as on Quartz Creek.

At Quartz Creek the bottoms of most rills were "paved" with small pebbles, gravel and angular rock. This feature was generally absent in the rills at Rock Creek, where the soils had a low stone content. It suggests a form of "surface armouring" (Megahan, 1972) and may account for the differential cutting rates on the two sites. Differences in precipitation characteristics may also be responsible for the greater number and degree of development of the Rock Creek rills.

4.4. Discussion

4.4.1. Review

This study began as an investigation of soil disturbance on groundskidded and cable-yarded clearcuts in the Nelson Forest Region. It was expanded to include an examination of soil characteristics of skid road-related disturbance. Thirty-one clearcuts (twenty-five groundskidded and six cable-yarded) were surveyed for disturbance and two were selected for the skid road analysis.

The study showed that summer and winter groundskidding generated 1.5 and 1.8 times more soil disturbance, respectively, than cable logging in corresponding seasons. Soil disturbance averaged 45.4 and 40.4% on summer and winter groundskidded sites, respectively, compared to 29.5 and 22.3% on summer and winter cable-yarded sites. As expected, most of the additional disturbance was caused by skid roads, which disturbed 28.8% of summer and 24.4% of winter groundskidded blocks but only 2.8% of all cable-yarded areas. There were other minor differences as well but these appeared to be due to specific logging situations rather than characteristics of the logging systems themselves. The

similarities between the logging systems, rather than the differences, were perhaps the most important features of the survey results.

Total soil disturbance proved to be a relatively weak indicator of the manner in which logging systems interact with the site to create soil disturbance. This was most clearly illustrated by its poor correlations with season of logging and slope steepness. A more specific index was needed. This study showed source and depth of disturbance were better than total soil disturbance at explaining logging system/soil disturbance relationships. For example, describing soil disturbance by its source explained why groundskidding caused more soil disturbance than cable yarding (more skid roads) and also emphasized fundamental similarities between the systems in terms of haul road and landing requirements. Distributions of soil disturbance by depth class were best explained by examining relationships between source and depth of disturbance. Thus the high level of very deep disturbance on winter cable-yarded sites was directly linked to a high haul road density, since haul roads were characterized by a high proportion of very deep disturbance. Similarly, the high level of light disturbance

on summer cable-yarded sites corresponded to high levels of yarding disturbance, most of which was classed as light.

Somewhat surprisingly, season of logging had no effect of soil disturbance levels. The most obvious "seasonal" differences (between summer and winter cable-yarded sites) were thought to be caused by other factors. Differences between summer and winter groundskidded blocks (in total, by source, or by depth) were small and offered no conclusive (i.e., statistically significant) proof that season of logging affected soil disturbance.

In terms of its statistical significance, slope steepness had a stronger effect than season of logging on soil disturbance. Even so, the effects were subtle. Although the data suggested that disturbance increased in both extent and depth with increasing slope, only two specific differences were found to be significant: (1) skid road-related disturbance was greater on slopes of more than 20% than on slopes of less than 20%; and (2) landing-related disturbance was greater on slopes of less than 40% than on slopes of more than 40 percent.

The second phase of the study demonstrated that soil disturbance associated with skid roads was accompanied by substantial shifts in the physical and chemical characteristics of the soils on the disturbed areas. Soils on skid road surfaces were 9 to 13% denser, had pH values 1.0 to 1.4 units higher, had 18 to 33% less organic carbon, and had fifteen-minute infiltration rates that were 30 to 85% lower than for undisturbed surface soils. In general this merely confirmed what other researchers have already reported in more detail elsewhere (Dyrness, 1965, 1967, 1972; Hatchell, Ralston and Foil, 1970; Lewis, 1968; Mace, 1970; Smith and Wass, 1979, 1980; Steinbrenner and Gessel, 1955; Youngberg, 1959). Its principal value was that it extended the range covered by previous studies into an area dominated by steep glaciated terrain and shallow soils.

4.4.2. Comparisons With Other Researchers

In general, soil disturbance levels recorded for this study fell within ranges reported for similar logging systems by other researchers (see Table 11). (Note that several of these studies have not included some sources or degrees of disturbance.) Average disturbance levels for summer and

Table 11. Comparison of mineral soil exposure generated by groundskidding, cable and aerial logging systems in British Columbia and northwest United States.

INVESTIGATORS	REGION	GROUND SKIDDING		CABLE SYSTEMS				AERIAL SYSTEMS		COMMENTS
		HORSE	TRACTORS	JAMMER	HIGHLEAD	GRAPPLE	SKYLINE	BALLOON	HELICOPTER	
Fowells and Schubert (1951)	Northern California	-	22%(s)	-	-	-	-	-	-	-
Garrison and Rummel (1951)	Eastern Oregon & Washington	12%	21 (s)	15%	-	-	-	-	-	-
Steinbrenner and Gessel (1955)	Southwestern Washington	-	26 (s)	-	-	-	-	-	-	Includes only skid roads.
Dyrness (1965, 1967, 1972)	Southwestern Oregon	-	35 (s)	-	31%(s)	-	12%(s)	6%(s)	-	-
Ruth (1967)	Western Oregon	-	-	-	16	-	6	-	-	-
Bockheim et. al. (1975)	Southwestern British Columbia	-	69 (s)	-	29	-	-	-	5%	Does not include haul roads and landings.
Hetherington (1976)	South-Central British Columbia	-	20 (w)	-	-	-	-	-	-	-
Klock (1975)	North-Central Washington	-	74 (s) 34 (w)	76		-	25	-	12	Area was salvage-logged after wildfire.
Clayton (1981)	Central Idaho	-	-	-	-	-	-	-	5	-
Utzig and Herring (1975)	South Coastal & Southeastern British Columbia	-	16	-	5	-	-	-	-	Recorded only disturbance deeper than 25 cm (very (deep).
Smith and Wass (1976)	Southeastern British Columbia	-	46 (s) 29 (w)	13 (s)	17 (s) 17 (w)	29%(s) 22 (w)	8 (s)	-	-	-
Hammond (1978)	Southeastern British Columbia	-	28 (s) 39 (w)	-	-	-	-	-	-	Does not include off-road (yarding) disturbance.
Schwab and Watt (1981)	Central British Columbia	-	45 (s) 49 (w)	-	-	12	-	-	-	Does not include haul roads and landings.
This Study	Southeastern British Columbia	-	45 (s) 40 (w)	-	31 (s) 26 (w)	27 (s) 20 (w)	-	-	-	-

winter tractor- and highlead-logged sites in this study are in the middle to upper parts of their respective ranges. There is good agreement among the four studies done in the Interior of British Columbia (Smith and Wass, 1976; Schwab and Watt, 1981; Hammond, 1978; this study). Disturbance estimates range from 28 to 46% for summer tractor-logging, and from 29 to 49% for winter tractor-logging. (The ranges are only approximate, however, because of different sampling criteria among these studies (see "comments" in Table 11).) This study showed much higher levels of disturbance for highlead systems than did Smith and Wass (1976) but similar levels for grapple yarding.

There is also relatively good agreement among researchers in terms of between-system differences. In general, all researchers agree that logging with tractors or rubber-tired skidders causes more soil disturbance than logging with cable or aerial systems. Aerial systems appear to cause the least disturbance, due at least in part to the fact that no haul road-related disturbance was recorded on the balloon- and helicopter-logged settings cited in Table 11. Obviously, even aerial systems require a road network within an economic flying range but they benefit from the fact that the roads do not necessarily have to extend into the cutting units.

In theory, if all environmental and other logging factors are held equal, total soil disturbance on cable-logged cutovers should decrease as yarding distance (and therefore haul road spacing) increases. If this held in practice then jammer systems, with the shortest average yarding distances of any cable system, should generate the highest levels of disturbance, followed by grapple-yarding (short to medium yarding distances, often with tailhold roads), highlead (medium yarding distances) and skyline systems (long yarding distances). Among the studies cited in Table 11, only skylines fit this theoretical framework. In most cases highlead systems cause the greatest disturbance, followed closely by grapple-yarding systems, while jammer systems cause only slightly more than half as much disturbance as highlead systems.

There are probably three major factors responsible for this discrepancy between theoretical considerations and actual measurements: (1) specific site conditions on the sampled areas; (2) geographic locations of the various studies; and (3) small sample sizes.

The effect of specific site conditions on soil disturbance is well demonstrated by this study. High values of yarding disturbance on summer cable-logged sites were attributed to

poor deflection over steep uniform slopes and to thin litter and duff layers on dry southerly exposures. By comparison yarding disturbance was much less on winter cable-logged sites as a result of gentler slopes, deeper duff layers and possibly the presence of protective snowpacks, but the shapes and locations of the cutblocks increased haul road densities.

Another example is given by Klock (1975), who reported disturbance values that were almost twice as high as found by other researchers for the same logging system. His study area was salvage-logged after a wildfire. Clearly the fire must have influenced the degree of soil disturbance to some extent, perhaps by destroying most of the protective litter layer on the forest floor.

Geographic location may also be an important factor to the extent that specific site conditions and logging requirements vary between regions. In particular, logging operations in coastal environments may not be directly comparable to those in interior environments, even for the same cable system. Among highlead operations, for example, Dyrness (1965) and Bockheim et al. (1975) reported disturbance estimates of 29 and 31%, respectively, for coastal

regions (the latter did not include haul roads and landings and it is not clear whether the former did either). In contrast Smith and Wass (1976) found substantially less soil disturbance (17% for both summer and winter) for interior highlead operations, even with haul roads and landings included. From observations made during field surveys, I feel that the figures given by Smith and Wass (1976) are more representative for highlead systems in the Nelson Forest Region.

Finally, sample sizes in most studies are small, and published information on some cable systems (such as jammer and grapple) is scarce. Most soil disturbance studies, including those restricted to small geographic areas, are characterized by high variability in disturbance estimates for individual cutovers. Consequently the base of information is probably too limited to develop representative disturbance estimates for all cable systems, particularly when comparisons between systems are compounded by introducing regional differences as well.

Groundskidding in winter does not seem to generate consistently less soil disturbance than in summer. This study and Smith and Wass (1976) both record less disturbance on

winter-logged sites, but Hammond (1978) and Schwab and Watt (1981) report the opposite. Therefore seasonal differences, if they exist, may not be effectively represented by the index of total mineral soil exposure. It is possible, for example, that soil disturbance under summer and winter conditions may differ in terms of soil properties, particularly bulk density and infiltration rate.[8]

Alternatively, given the apparent high level of variability in and between such studies, sample sizes may be too small to consistently describe seasonal differences.

Slope effects also appeared to be minor as well but are better documented than seasonal effects. Skid road-related disturbance in this study was significantly higher on moderate and steep slopes (greater than 20%) than on gentle slopes, while landing-related disturbance was significantly

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[8]Several winter-logged blocks were examined, with trial infiltration runs made and bulk density samples taken, when choosing the sites for the second phase of this study. The results were extremely variable and too inconsistent for a small-scale study, so consequently the second phase was restricted to summer-logged sites. On average, however, bulk densities were much lower and infiltration rates considerably higher on winter-built than on summer-built skid roads.

less on 40%+ slopes than on moderate and gentle slopes. These findings generally agree with Smith and Wass (1976), who reported that skid road disturbance was twice as high on slopes steeper than 60% than on gentler slopes for winter-logged but not summer-logged sites. Also, Garrison and Rummell (1951) found that on slopes greater than 40% soil disturbance levels were 2.8 times higher than on slopes less than 40 percent.

The studies of Hammond (1978), Schwab and Watt (1981) and Smith and Wass (1976) provide a substantial base of information to compare soil disturbance by source (see Table 12). The averages for each source differ somewhat between the studies but the ranges (in parentheses) are reasonably consistent. Smith and Wass (1976) record less average haul road, landing and yarding disturbance, but considerably more skid road disturbance, than the current study. However, tailhold roads on grapple-yarded clearcuts (Smith and Wass, 1976) are included in with skid roads. No tailhold roads were encountered on the grapple-yarded blocks surveyed in this study.

The figures for groundskidded clearcuts agree more closely, probably partly due to the larger sample sizes. All studies

Table 12. Comparison of studies giving soil disturbance as a percent of logged area by source[1].

	SOURCE OF DISTURBANCE (%)			
	HAUL ROADS	LANDINGS	SKID ROADS	YARDING
A. GROUNDSKIDDING				
Hammond (1978)				
- Summer	3.0	3.8	20.7	-
	(0.0-7.7)	(0.0-7.0)	(8.6-28.8)	-
- Winter	7.6	9.5	21.3	-
	(1.6-16.1)	(2.4-15.5)	(14.8-29.9)	-
Schwab & Watt (1981)				
- Summer	-	-	38.1	6.6
	-	-	(28.2-51.2)	(1.7-13.4)
- Winter	-	-	40.4	8.2
	-	-	(30.0-48.1)	(3.8-13.7)
Smith & Wass (1976)				
- Summer	7.6	0.7	31.6	3.6
	-	-	-	-
- Winter	2.9	0.6	17.8	4.7
	-	-	-	-
This Study				
- Summer	8.3	5.1	28.8	3.2
	(0.7-17.3)	(0.1-18.0)	(11.0-38.1)	(1.1-5.6)
- Winter	7.6	4.3	24.4	4.0
	(1.0-12.0)	(0.0-11.1)	(2.3-37.3)	(0.3-13.9)
B. CABLE SYSTEMS				
Hammond (1978)	-	-	-	-
Schwab & Watt (1981)				
- Summer/Winter	-	-	0.0	11.6
	-	-	(0.0)	(8.8-17.4)
Smith & Wass (1976)[2]				
- Summer	3.8	0.7	9.9[3]	3.5
	-	-	-	-
- Winter	2.5	0.0	16.6[3]	1.8
This Study				
- Summer	9.0	1.3	2.8	16.4
	(8.5-9.5)	(0.0-2.3)	(0.5-6.4)	(11.5-22.8)
- Winter	16.6	0.5	2.7	2.5
	(9.7-23.5)	(0.0-1.4)	(0.0-6.4)	(0.9-3.5)

[1]Ranges are in parentheses.
[2]Summer data include highlead, grapple and jammer yarding; winter data include highlead and grapple yarding.
[3]Includes tailhold roads and miscellaneous cat roads.

report that skid roads accounted for more than half of total soil disturbance (and between 60 and 70% for the two studies that measured all four disturbance sources). Haul roads are generally the second largest source of disturbance.

Disturbance depth distributions in this study were similar for both summer and winter groundskidded sites but differed between summer and winter cable-logged blocks, for reasons which were suggested earlier. More important, it was found that groundskidding caused significantly more deep and very deep disturbance than cable yarding. This was traced to the contribution of skid roads to total soil disturbance and the deep and very deep depth classes in particular.

Depth distributions for each disturbance source can be compared to only one other study (Smith and Wass, 1976) but fortunately their data base is large (see Table 13).

Smith and Wass' results agree well with this study for haul road, landing and yarding distributions, reporting slightly higher levels of light and deep disturbance but less very deep disturbance for each source. Therefore both studies show that haul roads and landings generate primarily very deep disturbance and that yarding disturbance is characteristically shallow.

Table 13. Comparison of depth-of-disturbance distributions by source.

	SOURCE OF DISTURBANCE			
	HAUL ROADS	LANDINGS	SKID ROADS	YARDING
Smith and Wass (1976)				
- shallow (<5 cm)	5.3%	9.0%	12.3%	75.7%
- deep (5-25 cm)	8.7	17.9	19.9	21.0
- very deep (>25 cm)	85.1	71.8	66.2	3.3
Current Study				
- shallow (<5 cm)	8.2%	9.7%	24.1%	82.3%
- deep (5-25 cm)	15.7	29.2	46.7	16.2
- very deep (>25 cm)	76.1	61.1	29.2	1.5

Smith and Wass (1976) found that skid roads also generate mostly very deep (>25 cm) disturbance whereas this study indicated skid road disturbance was mostly deep (5 to 25 cm). The difference in depth distribution may be related to the difference in average slopes of the clearcuts surveyed in the two studies (58% for Smith and Wass (1976), 33% in this study).

Finally, most soil disturbance surveys, again including this one, are characterized by a high degree of variability in their disturbance estimates, especially for groundskidding

systems. This also seems to apply between studies as well. Most studies have attempted to attribute some of the variation to major environmental influences (season of logging, slope steepness, and other factors to a lesser degree) but with inconclusive results. To date, researchers have not considered factors relating to the logging operation itself, such as its layout and organization, skidding patterns and methods, type and size of equipment, tree size and volume, and the logging crew itself. The effects of these factors on soil disturbance are therefore unknown at this time. It seems probable that future studies will have to consider some of these operational factors if reasons for the high variation are to be more fully understood.

The results of the second phase of the study are generally supported, although to varying degrees, by the findings of other researchers: Soil bulk densities were higher and infiltration rates lower for skid roads than for adjacent undisturbed soils, while other soil properties of skid road surfaces resembled subsoil more than surface soil conditions. Also, extensive rilling indicated that overland flow and surface erosion was occurring on the road surfaces in response to soil exposure and compaction.

Table 14 compares bulk density measurements of this study with similar studies in other parts of North America. All have found that logging traffic causes soil bulk density to increase. The degree of compaction ranges from 16 to 76% in the other studies while for this study the average degree of compaction was 9.5% for Quartz Creek soils and 12.8% for Rock Creek soils. There is no clear correlation between soil texture and degree of compaction evident in Table 14, presumably because of site-to-site differences in soil moisture conditions, traffic intensities and logging equipment.

This study differs with other researchers in reporting:

1. lower degrees of compaction; and
2. higher bulk densities for subsoils than for skid road surfaces.

These features may reflect differences in trail-building procedures, and consequently compaction processes, on gentle versus steep slopes. On gentle terrain the tractor or skidder does not necessarily have to excavate and build a running surface on which to travel. The compaction force is usually applied directly to the undisturbed soil, so the degree of compaction is a function of initial (undisturbed) and final bulk densities. On steep slopes, however, the

Table 14. Comparison of the effect of logging traffic on soil bulk densities.

INVESTIGATORS	STUDY REGION	SOIL TEXTURES[1]	SOIL BULK DENSITIES (g/cm^3) UNDISTURBED SURFACE	SUBSOILS[2]	ROAD SURFACE	PERCENT CHANGE[3]
Steinbrenner and Gessel (1955)	Southwestern Washington	-	-	-	-	+35.0%
Youngberg (1959)	Western Oregon	c - cl	0.88	0.93	1.55	+76.0
Dyrness (1965)	Western Oregon	"Medium- to Fine-Textured"	0.66	-	0.98	+48.5
Campbell, Willis and May (1973)	Georgia Piedmont	sl - cl	1.30	-	1.51[4]	+16.2
Dickerson (1976)	Coastal Plain, Northern Mississippi	ls - sicl	1.29	-	1.55	+20.2
Hassan (1978)	Coastal Plain North Carolina	s	0.37	0.70	0.50	+35.1
Froehlich (1979)	Western Oregon	-	0.97	1.03	1.14	+17.5
Adams and Froehlich (1981)	Western Oregon	-	0.66	0.88	1.12[5]	+69.7
Sidle and Drlica (1981)	Western Oregon	cl	0.49	0.65	0.68[6]	+38.8
This Study	Southeastern British Columbia	gsl (s)sil	1.09 1.35	1.57[7] 1.67[8]	1.19[9] 1.52[9]	+ 9.5 +12.8

[1]Terminology from Canada Soil Survey Committee (1978).
[2]Refers to C-Horizon generally.
[3](Road Surface ÷ Undisturbed Surface) X 100.
[4]Figure used is for primary skid trails.
[5]Estimated from Figure 2, p. 3.
[6]Estimated from data, Table 2, p. 1221.
[7]Compact morainal deposit.
[8]Slightly weathered siltstone.
[9]Averaged for full width of road surface.

tractor must excavate soil from one part of the skid road and build a fill slope with it on the outside. The compaction process begins on disturbed soils whose initial bulk densities are different from those of undisturbed soils. In the case of the excavated section of the skid road the initial bulk density may be higher than that of the undisturbed surface soil, while the bulk density of the sidecast or fill material is lower. Since bulk density is no longer homogeneous across the skid road cross-section, an average degree of compaction over the full road width will overstate compaction in some areas and understate it in others.

This situation seems to apply to the Quartz Creek and Rock Creek sites (see Figure 19). In both cases road surface bulk density decreases outward from the toe of the cut to the outer edge of the skid road. Bulk densities for the inner track and center zones are intermediate between the values for subsoils and undisturbed surface soils. The degree of compaction in these zones depends on whether road surface bulk densities are compared to subsoils, surface soils or a combined value, and can range from a small decrease (if compared to subsoils) to a moderate increase (if compared to undisturbed soils). The fill portion is less ambiguous; soil bulk densities in the outer track zone are

26 and 29% higher than their sidecast counterparts for Quartz Creek and Rock Creek, respectively.

Smith and Wass (1979, 1980) reported that soil pH increased with depth of cut on skid roads at a number of sites in interior British Columbia. They also found that subsoil textures of the <2 mm fraction were similar to surface soil textures. This study also found similar trends.

The infiltration tests run in this study are of limited value because of their short duration. Infiltration capacity curves generally describe a negative exponential function with time (Horton, 1940); the 15-minute infiltration rates are still on the steeply-sloping downward portion of the curve and cannot be reliably extrapolated for longer terms. However, relative differences between the undisturbed and skid road surfaces are of some interest. A loose comparison can be made with data given by Lewis (1968) in his study of infiltration capacities of undisturbed and skid road surfaces on two coarse glaciomarine soils in southwestern British Columbia. Fifteen-minute infiltration rates inferred from his data are (approximately) 18 cm and 15 cm for undisturbed soils and 9.5 cm and 3.2 cm for their respective on-road counterparts. The figures for this study are 26 cm and 18

cm for undisturbed Quartz Creek and Rock Creek soils, respectively, and 22.6 cm and 3.3 cm for skid road surfaces. Therefore 15-minute infiltration rates on skid road surfaces are only 53% and 21% of the rates for undisturbed surfaces in Lewis' (1968) study, compared with 87% and 18% for this study. The fine-textured Rock Creek soils, theoretically more susceptible to compaction than Quartz Creek soils, may partly explain the dramatic reduction in infiltration.

Rill erosion was more pronounced on the Rock Creek site than on the Quartz Creek site. On Quartz Creek, average rill length to 2.5 cm depth was 31.2 metres on an average slope of 29.6%, compared to an average of only 5.7 metres on a similar 27.2% slope for Rock Creek.

Kidd (1963) suggested that for similar skid road gradients (about 30%) erosion control structures should be spaced 40 feet apart on granitic soils and 60 feet apart on basaltic soils. If climatic conditions were assumed to be comparable (there is no basis for such an assumption) the results of this study would suggest that Quartz Creek soils are relatively less erodible and Rock Creek soils are more erodible than granitic or basaltic soils. Lack of good climatic information precludes more detailed comparisons of relative erodibilities.

4.4.3. Implications of Soil Disturbance to Forest Managers

Researchers have been guided in their interpretations of soil disturbance by general relationships between the extent and severity of soil disturbance and site degradation. Smith and Wass (1976) express a common sentiment in their statement,

> "Until further specific information is gained, we are assuming that any mineral soil exposure results in an increase in erodibility and that disturbance over 25 cm in depth (very deep classification) is potentially harmful to the site" (p. 32).

Their recommendations are consistent with this approach:

> "Some maximum extent and severity of soil disturbance on steep slopes will have to be considered. This limit will vary with the site (soil, climate, topography and stand composition), but even on the most stable soils, exposure of mineral soil in excess of 25 to 30% should be avoided on steep slopes. Very deep (over 25 cm) disturbance should be kept to as low a proportion of the total mineral soil exposure as possible" (p. 35).

Depth of disturbance is widely considered to be synonymous with severity of disturbance. In general, disturbance that is confined to the surface few centimetres of the soil (light disturbance in this survey) appears to have some silvicultural benefits as most conifers prefer mineral soil to duff or litter seedbeds. Scarification, for example, is essentially a technique to enhance natural regeneration by

generating light soil disturbance, and is recognized as a viable silvicultural prescription in most provinces. The Alberta Forest Service (1977) suggested that disturbance should cover about 20% of the area, be well distributed, and preferably consist of a mixture of duff and mineral soil. In some situations logging-generated disturbance may satisfy silvicultural goals. For example, Glen (1979) states that drag scarification is not normally required on summer-logged sites in the interior of British Columbia. However, since soil disturbance is generally a by-product rather than a goal of logging, its spatial distribution may not meet silvicultural requirements in all circumstances (Stewart, 1978).

Deep disturbance appears to have more limited value, while there is little doubt that very deep disturbance is detrimental to most forest sites. This is particularly true for soils on steep mountain slopes where the rooting zone is often shallow and subsoils are compacted, unweathered and relatively infertile. The results of the second part of this study outline some of the concerns associated with deep and very deep disturbance: altered chemical properties that may

exceed the tolerance limits of coniferous regeneration; exposure of denser or compacted soils that may limit root growth; and reduced infiltration capabilities that may render exposed soil more susceptible to overland flow and erosion.

Since very deep disturbance appears to be most harmful, forest managers should focus their planning efforts on reducing its extent and on rehabilitating severely-disturbed sites after logging. In this context quantitative soil disturbance information can be used as a tool to determine treatment methods and priorities, based on the source of disturbance and its relative importance as a contributor of deep and very deep disturbance. The results of this study suggest the following guidelines:

(1) Haul roads and landings are probably the most severely-disturbed sites on logged areas. More than 90% of disturbance associated with these sources is in the deep and very deep categories. The type of treatment required will be dictated by the intended period of use. If the road is a permanent part of the forest access network, treatments to control erosion are important. If the road (or landing) is only a temporary structure (eg. a spur), emphasis should be on restoring the site to a productive state.

(2) Skid roads on groundskidded sites are characterized by more light and deep but less very deep disturbance than haul roads or landings. However, they are also the largest contributors of disturbance of all depth classes. Since skid roads are

almost always abandoned after logging, the area occupied by them is available for timber growth; consequently treatments to restore such sites to a productive state should be considered. Erosion control is essential during the period required for vegetation to re-establish and stabilize the skid road surface.

(3) Yarding-disturbed areas are usually the least severely-disturbed sites on logged areas. Coupled with the fact that yarding generally represents a minor source of disturbance as well, specific treatments are probably not needed unless exceptional circumstances create extensive yarding disturbance.

4.4.4. Options For Minimizing the Detrimental Effects of Soil Disturbance

One of the most obvious ways to minimize soil disturbance (and one that is frequently suggested in the literature) is to adopt logging systems that generate lower levels of disturbance than systems currently in use. This solution has gained considerable support, to the point where alternative means are apparently forgotten. In practical terms this solution is often the most difficult one to implement effectively. An effective effort to reduce the levels or effects of detrimental disturbance must incorporate the following alternatives: (a) use logging systems that produce low quantities of very deep disturbance; (b) improve or

modify current logging systems through better planning and supervision; and (c) rehabilitate severely-disturbed areas when logging operations are completed.

(a) Use of Alternative Logging Systems

This approach is one of the solutions proposed by the Steep Slopes Guidelines (British Columbia Forest Service, 1973, 1974). In the context of the Nelson Forest Region, cable systems would replace groundskidding systems for logging slopes steeper than 50 percent. A switch from groundskidding to cable logging methods would virtually eliminate the need for skid roads. Since skid roads are the single largest contributor to total soil disturbance as well as to each depth category, substantial reductions in deep and very deep disturbance could be gained. The extent to which soil disturbance can be reduced by cable logging depends upon the choice of cable system and the care taken in layout and logging. A variety of cable yarding systems and machines are available, each with different yarding capabilities and haul road and landing requirements. Systems having applications for the Nelson Forest Region are: jammer yarders and long-boom cranes (highlead and gravity slackline); mobile

steel spars from 40 to 70 feet in height (highlead); and yarding cranes (highlead, slackline, running skyline or grapple-yarding) (Studier and Binkley, 1976; Larsen, 1978; Wellburn, 1975).

Jammer systems have the shortest yarding distance (200 to 500 feet uphill, less than 300 feet downhill) and therefore the highest road densities of any cable logging systems, but can work on narrow roads and small landings (Lysons, 1974). Grapple-yarding systems are usually limited to external yarding distances of 400 to 450 feet. Haul road densities are high, and wide roads are needed for these larger and heavier machines. Perimeter roads around the block add to soil disturbance if mobile tailhold spars are used (see Smith and Wass, 1976). On moderate slopes grapple yarders can windrow logs along the road side but on steep slopes they require landings to deck logs (Burke, 1972).

Highlead systems yard efficiently to 500 or 600 feet and can be extended to 700 feet or more if deflection is good. Haul road requirements vary with the size of the yarder. Some small yarders can operate on narrow roads but larger machines designed for coastal conditions require wide roads and adequate landings. Uphill yarding capability also varies with the type of yarder (Wellburn, 1974, 1975).

Slackline and running skyline systems are capable of yarding efficiently to distances of 1,000 to 1,200 feet (Wellburn, 1975) and thus can reduce haul road densities substantially (Burke, 1975; Lysons, 1976; Mann, 1977). Running-skyline yarders are capable of swinging and decking logs on haul roads but they are less effective at piling logs on landings. Since most of these yarders are large and heavy, they require wide roads to work on. Good landings are crucial to an efficient skyline yarding operation (Carson, 1976). Solid guyline and tailhold stumps are required for all cable systems and are especially important for larger machines and long-line systems which can impose very high loads on anchoring stumps.

Good logging layout is essential to taking full advantage of the capabilities of a yarding system. The engineer must plan for adequate roads, landings and deflection. The advantages of cable yarding systems in terms of reduced soil disturbance are lost if inadequate planning results in short (for the system) yarding distances and high haul road densities, or lack of adequate deflection with consequent high yarding disturbance (see Figure 21).

FIGURE 21. Yarding gouges resulting from poor deflection.

Although cable logging may cause less soil disturbance than groundskidding, the reduction is usually accompanied by considerably higher logging costs. For example, Wellburn (1975) estimated total logging costs per cunit for skidder, tractor and a variety of alternative cable systems, and determined that skidders were the least expensive ($6.25/Ccf), tractors the next least expensive ($9.03/Ccf), and cable

systems the most expensive ($9.93 to $12.91/Ccf). For poor logging chances (small wood, low volumes, and short operating seasons) skidder and tractor logging costs increased by about 70% but cable logging costs almost tripled. Cottell, McMorland and Wellburn (1976) reported felling, yarding and loading costs of $22 to $31 per cunit for cable systems versus $12 to $16 per cunit for groundskidding systems in a study of cable logging in interior British Columbia and Alberta.

(b) Modifications or Improvements to Existing Methods

It may be possible to reduce soil disturbance by altering current logging techniques rather than adopting different logging systems. Improved planning for and supervision of current logging systems and operations are essential. Murray et al. (1976) described the considerations and procedures required of loggers, supervisors and planners to minimize unnecessary soil disturbance on groundskidding operations. Some of the suggestions, such as the use of preplanned skid roads, offer opportunities for reducing the total length of skid road on groundskidded sites. Careful planning of haul roads for an entire development area,

rather than for individual cut blocks, is needed to minimize the total length of haul road for the development area. Figure 22 shows an example of a system of parallel haul roads planned to access a large development area.

FIGURE 22. Haul roads planned and located to access several clearcuts.

Froehlich, Aulerich and Curtis (1981) assessed the feasibility of planning skid road networks to reduce the portion

of commercially-thinned areas occupied by trails. Skid trail disturbance on a conventionally-logged control area was 20% compared to 11% when skid trails were spaced 100 feet apart, 7% when spaced 150 feet apart and only 4% when spaced 250 feet apart. Average winching distance was 32.8 feet in the conventionally-logged area, 34 feet on the area with 100-foot spacings, and 52.4 feet on the area with 250-foot spacings. Log production was not noticeably affected by increased trail spacings. Two groundskidded clearcuts, one having a random network of skid roads and the other a preplanned, pre-located network, are compared in Figures 23a and 23b, respectively. The former contains closely spaced skid roads with varying gradients and a range of skidding distances. Skid roads in the latter block are spaced further apart and are parallel to the contours. The skid roads are connected to the landings via steep feeder roads (see lower center portion of clearcut).

Opportunities for reducing site impact through the use of alternative groundskidding machines has received some attention in the Nelson Forest Region. Interest has been expressed in low-ground pressure tracked skidders with higher grade capabilities than wheeled skidders and crawler tractors. Powell (1978) reported that soil disturbance by these

a. Skid road network not preplanned.

b. Skid road network preplanned and pre-located prior to logging.

FIGURE 23. Comparison of random and pre-located skid road networks.

a. Skid road network not preplanned.
b. Skid road network preplanned and pre-located prior to logging.

machines was within acceptable limits, but skidding costs were higher than for conventional crawler tractors. McMorland (1980) examined the use of small (D-4 or equivalent) crawler tractors as compared to conventional-sized tractors (D-6) in the Nelson Forest Region. Total soil disturbance on blocks logged with the small tractors averaged about two-thirds of the level recorded for blocks logged with larger tractors. Haul road-, landing- and yarding-related disturbance was similar for both operations, while skid road-related disturbance on the blocks logged with small tractors was only about half the level found on the blocks logged with large tractors. Very deep disturbance caused by skid roads declined by one-third on summer-logged sites and by three-quarters on winter-logged sites. Reductions in skid road-related soil disturbance were attributed to the much smaller skid roads required for the smaller tractors.

(c) Rehabilitation of Severely-Disturbed Sites

A wide range of rehabilitation and erosion control techniques has been designed for forestry applications. The objectives of rehabilitation are generally twofold: (1) restore severely-disturbed sites to a productive state; and (2) erosion control.

Haul roads are perhaps the most severely-disturbed sites on logged areas and therefore are prime candidates for rehabilitation. However, with the exception of some dead-end spurs, haul roads are usually regarded as permanent structures and the land they occupy is considered removed from timber production. Because this withdrawal is permanent, emphasis should be placed on minimizing haul road densities within a development area through careful planning.

Rehabilitation measures for permanent haul roads will generally focus on erosion control, while restoring site productivity should be the goal in the case of temporary spurs which are abandoned after logging is completed. Erosion control is best considered in the planning and layout stages and implementation of controls should occur during construction. Once the road is built the success of erosion control measures depends largely upon the level and quality of road maintenance practices. A large body of literature describes road maintenance practices and rehabilitation techniques for erosion control in a variety of geographic and climatic settings (Packer and Christensen, 1964; Rothwell, 1971; Fisher and Taber, 1975; Megahan, 1974b, 1977; Carr, 1980; Haupt, 1959a; Kochenderfer, 1970).

Landings are distinct from haul roads in that they generally occupy a smaller proportion of logged areas than haul roads and are usually abandoned after logging. Rehabilitation measures are necessary to restore landing areas to productive tree growth as well as to reduce soil loss. These measures usually include grass-seeding, fertilization and soil ripping or tilling to counteract compaction (Adams and Froehlich, 1981; Gjertson, 1949). The British Columbia Ministry of Forests now requires landings to be rehabilitated following logging operations in most Interior regions.

Skid roads are less deeply disturbed than haul roads or landings, but are the major source of soil disturbance on groundskidded clearcuts and, on average, cause more very deep disturbance than all other sources. Skid road surfaces, at least on summer-logged sites, were generally compacted and resembled subsoils in their chemical and physical properties. As a result, skid roads probably have a greater impact on groundskidded sites than all other sources. Numerous studies have described extensive erosion on skid roads (Garrison and Rummell, 1951; Smith and Wass, 1976; Dickerson, 1975; U.S. Forest Service, 1953; Kidd, 1963) and reductions in seedling growth on compacted skid roads (Smith and Wass, 1979, 1980; Youngberg, 1959). Since

skid roads are intended to revert to timber production after logging, rehabilitation measures must be designed both to control soil erosion in the short term and to restore the sites to a productive state.

Some soil loss must be expected during and following logging. Considerable losses may occur during logging operations (Hoover, 1945; U.S. Forest Service, 1953). Most subsequent erosion occurs within the first year after logging (Megahan, 1974a; Megahan and Kidd, 1972b; Leaf, 1974). Therefore any delay in applying erosion control measures reduces the efficiency of the rehabilitation effort. Short-term erosion control techniques coupled with longer-term methods offer the best chance of success. In general, short-term methods stress control of surface runoff while longer-term methods emphasize revegetation of disturbed surfaces. Several publications describing erosion control techniques for skid roads and haul roads are available (Haupt, 1959a; Kidd, 1963; Murray et al., 1976; Packer and Christensen, 1964; Carr, 1980).

To date there has probably been more emphasis in the Nelson Forest Region on controlling erosion from skid roads than on restoring site productivity. The recent studies of Smith

and Wass (1979, 1980) define the implications of skid roads on tree growth and site productivity in this region. In their most recent work the authors have developed a system for rating sites according to their potential for site loss (Smith and Wass, 1980). Fine-textured calcareous soils (similar to those of Rock Creek) suffer the greatest losses. Efforts to restore productivity must take these differential site responses into account.

5. SUMMARY AND CONCLUSIONS

5.1. Summary

Soil disturbance was measured on thirty-one logged areas in the Nelson Forest Region of British Columbia in the first part of this study. In the second phase, physical and chemical properties of skid road surface soils were measured and compared with adjacent undisturbed surface soils and subsoils, and rill erosion on skid roads was correlated with slope gradient and length.

The sampled clearcuts occupied a range of slopes, aspects, elevations and biogeoclimatic zones but the majority were in high-elevation mixed stands of Englemann spruce and sub-alpine fir. Twenty-five of the thirty-one clearcuts were logged with rubber-tired skidders or crawler tractors of various size classes. Fifteen of the groundskidded sites were logged under "winter" conditions (on snowpacks and/or frozen ground) and ten were logged under "summer" conditions (on bare, unfrozen ground). Average sideslopes for the groundskidded blocks ranged from 5.2 to 52.4 percent.

Six clearcuts were logged by cable methods -- three by

highlead systems and three by grapple-yarding systems. The cable-yarded blocks were equally split between summer and winter operations. Average sideslopes ranged from 32.1 to 74.2 percent.

Groundskidding was found to cause significantly more soil disturbance than cable-yarding. For summer logging operations groundskidding caused an average of 45.4% disturbance (range 28.8 to 65.0%) compared to an average of 29.5% (range 21.5 to 39.9%) for cable-yarded clearcuts. Under winter conditions groundskidding generated an average disturbance of 40.4% (range 13.7 to 52.6%) while cable-yarding caused an average disturbance of 22.3% (range 12.3 to 28.4%).

Skid roads were the largest contributor of soil disturbance on summer and winter groundskidded clearcuts (28.8 and 24.4%, respectively, in absolute terms) but were a minor component on cable-yarded sites (2.8 and 2.7% on summer- and winter-logged sites, respectively). Haul roads were the second major source of disturbance on groundskidded clearcuts (8.3% in summer and 7.6% in winter) and overall were the largest contributor on cable-yarded blocks (9.0% in summer and 16.6% in winter). Landings contributed less disturbance than haul roads: 5.1 and 4.3% on summer and

winter groundskidded sites; and 1.3 and 0.5% on summer and winter cable-yarded sites, respectively. Yarding contributed the least to total disturbance of the four sources on groundskidded sites (3.2% for summer and 4.0% for winter) and was the third largest contributor overall (ahead of landings) on cable-yarded sites (16.4% in summer and 2.5% in winter).

The surveys confirmed the opinion that skid roads would be the largest contributor of soil disturbance on groundskidded sites. The purpose of the skid roads on the cable-yarded sites was not always evident but it appeared that tractors were occasionally used to log areas of poor deflection. Landings caused slightly more soil disturbance on groundskidded than on cable-yarded sites. With the exception of one anomalous value in each category, disturbance levels for haul roads and landings were similar for the two logging systems. The high value of haul road-related disturbance on winter cable-logged sites was thought to be a function of cutblock layout and haul road spacing, while the high level of yarding-related disturbance on summer cable-logged blocks appeared to reflect adverse site conditions (uniform, steep slopes, dry sites and thin duff layers).

More disturbance was classed as very deep on summer than on winter groundskidded blocks (19.2% versus 13.6%) but amounts of light and deep disturbance were similar. Summer cable-yarded sites were characterized by more light (15.1%) than deep (5.5%) or very deep disturbance (8.9%), contrasting with winter cable-logged blocks which featured more very deep (14.3%) than light (4.3%) or deep disturbance (3.7%). The most noticeable difference between logging systems was the higher level of deep disturbance on groundskidded as compared to cable-yarded clearcuts.

Source and depth of disturbance were found to be strongly correlated, with each disturbance source having a unique and characteristic depth distribution that was independent of logging system and logging season, and only marginally influenced by slope steepness. Haul roads and landings generated mostly very deep disturbance but very little light disturbance (they differed in absolute amounts, however). Skid roads created mostly deep with lesser amounts of very deep and light disturbance. Yarding was characterized as mostly light disturbance with minimal levels of very deep disturbance.

Season of logging had no significant effect on soil disturbance levels, although it was noted that winter logging generated 5% less (in the case of groundskidded systems) to 7% less (in the case of cable-yarding systems) disturbance than corresponding summer operations. Differences between summer and winter cable-yarded sites were thought to be due to adverse site conditions and cutblock layouts rather than to seasonal effects.

Overall, slope steepness did not significantly influence total soil disturbance levels on groundskidded clearcuts but did affect levels of skid road- and landing-related disturbance. The survey showed that skid roads generated significantly more disturbance on moderate and steep slopes (slopes over 20%) than on gentle slopes. Landing-related disturbance decreased with increasing slope, however, with significantly less disturbance on steep (40%+) than on gentle or moderate slopes. The survey showed a shift toward deeper average disturbance with increasing slope on groundskidded sites, the trend being especially well-developed on winter-logged sites. This trend was not statistically significant, however. The depth profile of skid road-related disturbance was strongly shifted toward deeper disturbance but the profiles of other sources showed little or no slope effect.

The second phase of the study demonstrated that skid road-related disturbance was also associated with substantial shifts in a variety of soil properties. Soil pH, carbonate content, and bulk densities were higher and infiltration rates and organic carbon were lower for soils on the skid road surfaces than for adjacent undisturbed soils. Bulk densities of skid road surfaces averaged 9.5 and 12.8% higher than for undisturbed soils on the Quartz Creek and Rock Creek areas, respectively. Infiltration rates of skid roads were 87% of rates for undisturbed soils in coarse-textured Quartz Creek soils, but only 21% in fine-textured Rock Creek soils. In general the skid road surfaces resembled subsoils more than surface soils in their physical and chemical properties. The direction of these shifts, if not the magnitudes, were regarded as unfavourable in terms of seedling survival and growth and erosion risk.

Rill erosion was much more advanced on the Rock Creek than on the Quartz Creek site. Rills achieved a 2.5-cm depth in 5.2 metres on 27% slopes on Rock Creek soils, compared with 31.2 metres on 30% slopes on Quartz Creek soils. Average volume of material eroded per metre of rill length was almost twice as high on Rock Creek as on Quartz Creek (5 044 cm^3/m versus 2 670 cm^3/m). These observations were

consistent with the generally-held view that fine-textured soils are inherently more erodible than coarse-textured soils. Also, the development of an "ercsion pavement" of pebbles and angular rock fragments may have retarded rill erosion on the Quartz Creek site. No such pavement was observed in the Rock Creek rills.

5.2. Conclusions

The results of this study support the widely-held view that groundskidding logging systems usually disturb soils on a larger proportion of the logging area than do cable logging systems. This survey suggests that the difference in areal extent is between 15 and 18% in absolute terms.

The additional disturbance is due to the need for skid roads. Skid roads form an integral part of the log transport process in groundskidding systems, particularly where slope steepness approaches or exceeds the terrain capabilities of tractors and rubber-tired skidders.

Skid roads contribute more very deep and deep soil disturbance than any other source. Since these depth classes,

particularly the very deep category, are most strongly associated with potentially detrimental effects in terms of soil erosion and site productivity, efforts to minimize the environmental impacts of groundskidding systems must clearly concentrate on skid roads. A twofold emphasis is suggested: (1) erosion control measures should be applied as soon as possible after logging is completed; and (2) skid roads should be rehabilitated to restore their timber-growing potential.

Based on this survey, groundskidding and cable yarding systems are similar in other respects insofar as source of disturbance is concerned. Both systems require haul roads and landings and, on average, have similar road densities. Certain cable (running-skyline or grapple-yarding) systems appear to offer some advantage over highlead methods in that the haul road can double as a log deck or landing, but they also characteristically employ shorter yarding distances and therefore narrower road spacings. The opportunity for reducing haul road- and landing-related soil disturbance by favouring cable over groundskidding methods therefore appears to be limited.

Yarding-related disturbance is minor in both extent and severity and, except under unusual circumstances, does not appear to constitute a serious problem on logged sites.

Season of logging and slope steepness appear to have much less influence on soil disturbance levels than is commonly credited to them. The extreme range in soil disturbance estimates suggests that several factors in addition to the ones considered here exert strong influences on soil disturbance levels. These may be related to site conditions (for example, aspect and its effect on site moisture status, depth of duff layers) or to logging conditions (timber size and density, type and size of logging equipment, road location and cutblock layout, and supervision and logging crew experience and attitudes).

The usefulness of soil disturbance information for planning and decision-making purposes will remain limited until some of these additional factors are identified and their effects on soil disturbance levels are defined.

6. RECOMMENDATIONS

This study has attempted to identify and explain statistically significant differences in soil disturbance (in terms of levels, sources and depths) between groundskidding and cable yarding logging methods. It has also attempted to associate changes in soil physical and chemical properties with key disturbance characteristics of source and depth. During the course of this study certain limitations of this form of survey, as well as topics requiring further research, have been recognized. These will be discussed briefly in this section.

During the field surveys it became apparent that soil disturbance levels were influenced strongly by operational (as opposed to environmental) factors such as cutblock layout, haul road and landing locations, size of groundskidding machinery, and characteristics of the timber stand. This survey (and most other soil disturbance surveys as well) placed more emphasis on environmental factors (slope, season of logging), however, and was not well suited to discern operational effects. Consequently the survey results were characterized by large unexplained variations in disturbance estimates within the major logging method/logging season

groupings, variations which reduced the effectiveness of the subsequent statistical analyses.

Further research into soil disturbance levels on logged areas must account for the potentially large influence of operational factors. Observations made during this field survey suggest that the key factors to consider (in addition to method of logging and source and depth of disturbance) are: haul road and landings specifications; size of equipment used (particularly for groundskidding systems); average skidding or yarding distances; and timber stand characteristics (tree size, piece size, volume per hectare). Depending upon study objectives, other stratification criteria may be needed as well.

The second phase of this study was intended as a descriptive adjunct to the soil disturbance survey rather than as a comprehensive analysis of the relationships between soil disturbance and its effects on site quality. It suggests that soil disturbance associated with skid roads is accompanied by substantial shifts in several soil properties and characteristics. However, the sample is too small to generalize over the full range of site conditions. Further study into the relationships between soil disturbance and soil

property changes is recommended, with emphasis on disturbed areas which will revert to timber production following logging.

No attempt was made to correlate the type or depth of soil disturbance with a quantitative estimate of site loss. This information is needed, however, in order to assess the effects of forest management practices and to choose from among a range of alternative logging and site improvement techniques. The recent studies of Smith and Wass (1979, 1980) are encouraging steps in this direction.

Finally, it was noted during the field surveys that post-harvesting treatments to control surface erosion and to restore disturbed areas to a productive state were applied sporadically. Extensive research has been done in other areas to develop practical and inexpensive site rehabilitation techniques. These may have to be modified slightly to suit local conditions and requirements, but most of the basic research has already been done and is available now. A program to test the effectiveness of the most promising techniques (as well as new ones as they are developed), and to modify them, if necessary, is essential.

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APPENDIX I

COPIES OF LETTERS FROM DISTRICT FORESTER,

NELSON FOREST DISTRICT,

TO ALL

T.F.L., T.S.H.L., T.S.L. LICENSEES AND CONSULTANTS.

I-1: DATED JUNE 18, 1973

I-2: DATED OCTOBER 4, 1974.

I-1

Nelson
June 18, 1973

Silviculture Sup., T.F.L. Sup.
T.S.H.L. Sup., P.S.Y.U. Sup.

ALL T.F.L., T.S.H.L., T.S.L. LICENSEES & CONSULTANTS:

Dear Sir(s):

Much of the remaining mature timber in the Nelson Forest District is located on steep to very steep slopes. The use of ground skidding systems on steep slopes can be damaging to the soil and drainage pattern, therefore, we must be more critical of the logging method to be employed on these areas, and this letter is written to give you notice that we will be examining your proposed logging system more closely in future.

As of today, ground skidding systems will not be approved on a new application over areas having a general slope in excess of 70% and areas having slopes between 50-70% will be more critically assessed for possible adverse effects. Areas over which an application has been accepted or plan has already been approved will be reassessed. After January 1, 1974, cable logging systems or an acceptable substitute will be mandatory on any area where soils, slope, vegetation, aspect, drainage, climatic or other conditions render the site subject to excessive environmental damage.

As a rough guide, ground yarding systems will not be approved for areas having slopes over 50% although exceptions may be made in specific cases for winter logging on the snow. The soil is the basic resource of the forest insofar as all uses are concerned and it is too valuable to allow undue damage. It is realized that special equipment and crews may be necessary for cable logging and if applicants cannot provide the system for the area, it may have to be reserved for cutting until approved systems are provided.

When submitting the application, the applicant will have to indicate on a contour map, these areas on which he plans to use a cable system in order that field staff can comment. This information is also necessary to allow recognition of extra costs of cable yarding in the appraisal. Although we specify the using of a cable system of logging for the steep slopes, we are open for proposals of other logging systems that will protect the area during logging.

Your consideration will be appreciated.

Yours truly,

J. R. Johnston, R.P.F.,
District Forester

JRJ/sw

Nelson
V1L 4C6
October 4, 1974

M. Cable Logging

ALL T.F.L., T.S.H.L., T.S.L. LICENSEES,
& FORESTRY CONSULTANTS,
NELSON FOREST DISTRICT.

Dear Sir(s):

This is further to our letters of June 18 and July 23, 1973 pertaining to ground skidding restrictions in Nelson Forest District.

The intent of this letter is to explain our current Nelson Forest District policy and the procedure to be followed where cutting plans are submitted covering areas of steep slopes or fragile ground where some logging method other than ground skidding should be implemented.

<u>Policy</u> - The present policy in this regard is as follows:

(1) <u>Cutting Permit applications covering an area with a general slope in excess of 70 percent</u>.

- We will disallow an application over an area where the average slope exceeds 70 percent unless cable logging or some other reasonable alternative method of logging is planned that will leave the site environmentally acceptable.

(2) <u>Cutting Permit applications covering an area with a general slope of between 50 and 70 percent</u>.

- Where there is an application over an area that has an average slope of between 50 and 70 percent, the licensee must supply a satisfactory explanation to justify logging by conventional ground skidding systems. Soil Stability must be proven before timber removal by ground skidding methods will be approved.

(3) <u>Cutting Permit applications covering an area with a general slope of less than 50 percent</u>.

- On an area of fragile ground conditions where soil stability may present a problem we may insist on a cutting plan that makes provision for cable logging or a reasonable alternative method of logging over all or a portion of the cutting area involved.

...........2

(4) Cutting Plans

- We expect licensees to submit acceptable cutting plans with maps that include such information as contours, topographic features, forest and non-forest types, method of logging - eg. ground skidding and/or cable logging, cut blocks, reserve areas, cutting sequence, landing locations, as well as a clear delineation of all main, secondary and branch roads and the state of completion.

Procedure

Where an *alternate method of logging may be necessary on a particular area the procedure as outlined below should be followed:

(1) Assess the area carefully on the ground in respect to the feasibility and suitability of an *alternate logging method and discuss the proposed cutting plan with the local Ranger.

(2) Where an *alternate method of logging is definitely planned on an area, the particular site should be clearly delineated on the cutting plan map.

(3) Submit the cutting plan including the pertinent appraisal information along with the map showing the area to be logged by an *alternate method.

A clear definition of cutting methods, eg. ground skidding and/or cable logging for specific areas must be embodied within the cutting plan or the plan will have to be immediately rejected.

To encourage the development of *alternate logging systems, costs of such systems should be documented where available and brought to the attention of the local Ranger in order that any reasonable cost estimates may be used for appraisal purposes.

Normally, if a portion of the area is to be cable logged, we will prorate the cable yarding cost with the conventional ground skidding cost on a per cunit basis.

Upon final processing in the Nelson Forest District office the cutting permit document will be issued incorporating the specific conditions relevant to the method of logging.

Yours truly,

J. R. Johnston,
District Forester

*N.B. - Where the term "alternate method of logging" is referred to above, it shall be construed to mean any form of cable logging or any other logging method other than conventional ground skidding systems.

c.c. All Rangers
c.c. Zone Supervisors
c.c. H.Q. Personnel

APPENDIX II

PHYSICAL DESCRIPTIONS OF CUTOVERS SURVEYED

FOR SOIL DISTURBANCE.

Table II-1. Physical descriptions of cutovers surveyed for soil disturbance.

BLOCK NUMBER	BLOCK LOCATION	YEAR OF LOGGING	METHOD OF LOGGING	SEASON OF LOGGING	BIOGEOCLIMATIC ZONE[1]	ELEVATION (m)	SLOPE (%) RANGE	SLOPE (%) MEAN
0101	Grizzly Creek	1974	Groundskidding	Summer	ESSF	1 450	0- 90	37.2
0102	Grizzly Creek	1974	Highlead	Winter	ESSF	1 350	20- 70	40.8
0103	Brodie Creek	1974	Highlead	Summer	ESSF	1 425	20-100	60.7
0104	Hoder Creek	1975	Groundskidding	Winter	ESSF	1 450	0-100	47.4
0105	Grizzly Creek	1975	Groundskidding	Winter	ESSF	1 400	30- 80	52.4
0106	Shannon Creek	1976	Grapple	Winter	ESSF	1 400	10- 60	32.1
0201	Poplar Creek	1973	Groundskidding	Summer	ESSF	1 575	10- 90	48.3
0202	Duncan River	1976	Groundskidding	Winter	IWH	925	0- 20	5.8
0203	Glacier Creek	1973	Groundskidding	Winter	ESSF	1 700	10- 70	27.6
0301	Lamb Creek	1976	Grapple	Winter	ESSF/IDF	1 475	30- 80	49.4
0302	Lamb Creek	1976	Groundskidding	Summer	IDF	1 050	0- 70	12.8
0303	Dewar Creek	1975	Groundskidding	Summer	ESSF	1 200	0- 80	31.3
0304	Hellroaring Creek	1976	Groundskidding	Summer	IDF	1 150	0- 50	15.9
0305	Hellroaring Creek	1975	Groundskidding	Winter	IDF	1 225	30- 60	37.5
0306	Nicol Creek	1975	Groundskidding	Winter	ESSF	1 975	10- 70	32.9
0307	Nicol Creek	1975	Groundskidding	Winter	ESSF	1 900	10- 70	32.1
0308	Rock Creek	1975	Groundskidding	Summer	IDF	1 275	30-120	47.5
0309	Kid Creek	1976	Grapple	Summer	ESSF/IDF	925	30- 70	50.0
0401	Lower Palliser River	1976	Groundskidding	Winter	IDF	1 375	0- 40	9.9
0402	Lower Palliser River	1976	Groundskidding	Winter	ESSF/IDF	1 525	30- 70	45.6
0403	Lower Palliser River	1975	Groundskidding	Summer	IDF	1 375	0- 40	15.5
0404	Campbell Creek	1976	Highlead	Summer	IDF/ESSF	1 275	50- 90	74.2
0405	Hall Lakes	1976	Groundskidding	Winter	IDF	925	0- 30	9.7
0406	Hall Lakes	1976	Groundskidding	Winter	IDF	925	0- 30	5.2
0501	Quartz Creek	1975	Groundskidding	Winter	IWH	1 375	20- 50	26.3
0502	Quartz Creek	1975	Groundskidding	Winter	ESSF	1 625	0- 80	32.8
0503	Quartz Creek	1975	Groundskidding	Summer	ESSF	1 875	10- 50	18.3
0504	Dainard Creek	1975	Groundskidding	Winter	IDF/ESSF	1 100	0- 50	24.0
0505	Dainard Creek	1975	Groundskidding	Winter	IDF/ESSF	1 100	0- 50	15.5
0506	Copper Creek	1975	Groundskidding	Summer	ESSF	1 625	10- 60	29.4
0507	Copper Creek	1975	Groundskidding	Summer	IWH/ESSF	1 375	20- 80	41.3

[1]Biogeoclimatic zones from Krajina and Brooke (1970):
IDF - Interior Douglas-fir
IWH - Interior Western Hemlock
ESSF - Englemann Spruce/Subalpine Fir

APPENDIX III

SOIL DISTURBANCE SURVEYS:

TABLES OF RAW (PERCENT) AND

TRANSFORMED (DEGREE) DATA USED

FOR ANALYSIS OF VARIANCE COMPARISONS.

Table III-1. Soil disturbance data (percent) for ANOVA test #1: Cable-yarding versus groundskidding on slopes greater than 20%.

LOGGING METHOD	LOGGING SEASON	BLOCK NUMBER	HAUL ROADS			LANDINGS			SKID ROADS			YARDING		
			LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP
CABLE-YARDING	SUMMER	0103	1.0	0.5	7.8	0.0	0.0	0.0	0.0	0.5	0.0	9.5	2.0	0.0
		0309	1.0	2.3	5.2	0.8	0.0	1.5	0.0	0.5	1.0	9.6	4.3	0.3
		0404	0.8	1.3	6.9	0.1	0.2	1.2	0.6	3.2	2.7	21.3	1.5	0.0
	WINTER	0102	2.9	2.4	11.4	0.0	0.0	0.0	0.6	3.8	1.9	2.9	0.3	0.0
		0106	1.0	1.0	7.7	0.0	0.0	0.0	1.1	0.6	0.0	0.9	0.0	0.0
		0301	0.3	2.3	20.9	0.0	0.5	0.9	0.0	0.0	0.0	3.2	0.3	0.0
GROUND-SKIDDING	SUMMER	0101	1.9	2.4	7.8	0.0	0.0	1.5	4.9	4.5	1.6	3.4	0.8	0.0
		0303	0.4	0.5	3.0	0.1	0.9	3.3	8.0	13.6	10.4	2.4	0.5	0.5
		0506	0.1	1.1	9.6	0.1	0.3	4.1	6.7	18.8	7.8	0.8	0.5	0.0
		0201	0.5	1.1	3.3	0.0	0.0	0.3	5.9	9.6	11.7	1.5	0.1	0.0
		0308	0.3	0.9	4.4	0.0	0.0	0.1	3.6	11.4	22.4	3.0	0.8	0.6
		0507	1.1	1.6	14.6	0.0	0.0	2.5	5.0	13.3	17.9	2.4	1.5	1.0
	WINTER	0202	2.2	3.3	6.5	0.0	0.0	0.0	5.9	7.2	2.3	2.6	0.6	0.0
		0305	0.4	0.9	7.0	0.1	2.4	5.8	5.3	16.1	10.6	1.6	0.6	0.3
		0306	0.1	0.6	9.6	0.3	1.4	4.6	7.6	17.5	9.6	0.6	0.3	0.0
		0307	0.0	2.8	6.6	0.0	0.1	0.8	5.5	17.5	8.7	1.9	0.6	0.1
		0501	0.4	1.5	5.3	0.0	0.8	7.2	5.5	15.5	2.1	1.5	0.7	0.1
		0502	0.0	0.4	0.6	0.0	1.1	2.5	3.1	17.4	9.5	0.3	0.0	0.0
		0504	0.3	2.0	7.8	0.5	1.7	2.7	7.7	18.0	3.2	1.3	0.4	0.2
		0104	0.4	1.0	5.2	0.0	0.0	0.0	7.3	10.5	5.1	2.8	0.4	0.4
		0105	0.9	1.5	8.9	0.0	0.0	0.0	9.2	15.4	9.3	5.0	0.0	0.1
		0402	0.4	0.3	9.5	0.0	0.0	4.5	3.5	15.8	18.5	0.3	0.0	0.0

Table III-2. Soil disturbance data (degrees) for ANOVA test #1: Cable-yarding versus groundskidding on slopes greater than 20%.

LOGGING METHOD	LOGGING SEASON	HAUL ROADS LIGHT	HAUL ROADS DEEP	HAUL ROADS VERY DEEP	LANDINGS LIGHT	LANDINGS DEEP	LANDINGS VERY DEEP	SKID ROADS LIGHT	SKID ROADS DEEP	SKID ROADS VERY DEEP	YARDING LIGHT	YARDING DEEP	YARDING VERY DEEP
CABLE-YARDING	SUMMER	5.7	4.1	16.2	0.0	4.1	0.0	0.0	0.0	0.0	18.0	8.1	0.0
		5.7	8.7	13.2	0.0	4.1	5.7	5.1	0.0	7.0	18.0	12.0	3.1
		5.1	6.5	15.2	4.4	10.3	9.5	1.8	2.6	6.3	27.5	7.0	0.0
	WINTER	9.8	8.9	19.7	4.4	11.2	7.9	0.0	0.0	0.0	9.8	3.1	0.0
		5.7	5.7	16.1	6.0	4.4	0.0	0.0	0.0	0.0	5.4	0.0	0.0
		3.1	8.7	27.2	0.0	0.0	0.0	0.0	4.1	5.4	10.2	3.1	0.0
GROUND-SKIDDING	SUMMER	7.9	8.9	16.2	12.8	12.2	7.3	0.0	0.0	7.0	10.6	5.1	0.0
		3.6	4.1	10.0	16.4	21.6	18.8	1.8	5.4	10.5	8.4	4.1	4.1
		1.3	6.0	18.0	15.0	25.7	16.2	1.8	5.1	11.5	5.1	4.1	0.0
		4.1	6.0	10.5	14.1	18.0	20.0	0.0	0.0	3.1	7.0	1.8	0.0
		3.1	5.4	12.1	10.9	19.7	28.2	0.0	0.0	1.8	10.0	5.1	4.4
		6.0	7.3	22.5	12.8	21.4	25.0	0.0	0.0	9.1	8.9	7.0	5.7
	WINTER	8.5	10.5	14.8	14.1	15.6	8.7	0.0	0.0	0.0	9.3	4.4	0.0
		3.6	5.4	15.3	13.3	23.7	19.0	1.8	8.9	13.9	7.3	4.4	3.1
		1.8	4.4	18.0	16.0	24.7	18.0	3.1	6.8	12.4	4.4	3.1	0.0
		0.0	9.6	14.9	13.6	24.7	17.2	0.0	1.8	5.1	7.9	4.4	1.8
		3.6	7.0	13.3	13.6	23.2	8.3	0.0	5.1	15.6	7.0	4.8	1.8
		0.0	3.6	4.4	12.1	24.7	18.0	0.0	6.0	9.1	3.1	0.0	0.0
		3.1	8.1	16.2	16.1	25.1	10.3	4.1	7.5	9.5	6.5	3.6	2.6
		3.6	5.7	13.2	15.7	18.9	13.1	0.0	0.0	0.0	9.6	3.6	3.6
		5.4	7.0	17.4	17.7	23.1	17.8	0.0	0.0	0.0	13.0	0.0	2.6
		4.1	3.1	18.0	10.8	23.5	25.5	0.0	0.0	12.2	3.1	0.0	0.0

Table III-3. Soil disturbance data (percent) for ANOVA test #2: Summer and winter groundskidding on slopes <20%, 20-40%, and >40%.

			SOIL DISTURBANCE ASSOCIATED WITH											
			HAUL ROADS			LANDINGS			SKID ROADS			YARDING		
LOGGING SEASON	SLOPE CLASS	BLOCK NUMBER	LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP
Summer	0-20%	0302	0.0	0.7	0.0	0.3	1.2	0.0	15.5	7.7	0.8	3.3	0.4	0.0
		0304	0.2	2.4	9.4	0.6	6.2	5.1	6.7	20.5	10.9	1.4	0.5	0.0
		0403	0.3	0.8	5.0	0.7	2.9	2.4	6.3	4.7	1.9	3.7	1.6	0.3
		0503	0.0	1.6	7.9	1.3	3.3	13.4	6.9	22.3	7.2	0.9	0.2	0.0
Summer	20-40%	0101	1.9	2.4	7.8	0.0	0.0	1.5	4.9	4.5	1.6	3.4	0.8	0.0
		0303	0.4	0.5	3.0	0.1	0.9	3.3	8.0	13.6	10.4	2.4	0.5	0.5
		0506	0.1	1.1	9.6	0.1	0.8	4.1	6.7	18.8	7.8	0.8	0.5	0.0
Summer	40%+	0201	0.5	1.1	3.3	0.0	0.0	0.3	5.9	9.6	11.7	1.5	0.1	0.0
		0308	0.3	0.9	4.4	0.0	0.0	0.1	3.6	11.4	22.4	3.0	0.8	0.6
		0507	1.1	1.6	14.6	0.0	0.0	2.5	4.9	13.3	17.8	2.4	1.5	1.0
Winter	0-20%	0202	2.1	6.0	3.2	0.1	0.8	0.3	13.5	8.5	4.9	6.4	3.6	0.7
		0401	0.6	5.1	2.4	0.2	7.1	3.8	8.1	1.9	0.9	13.6	0.3	0.0
		0405	0.8	1.3	0.7	3.7	3.6	1.9	2.3	2.9	1.1	5.7	1.3	0.3
		0406	0.8	2.1	1.1	1.9	1.6	0.0	1.7	0.4	0.2	3.5	0.3	0.1
		0505	0.1	0.4	1.4	0.0	2.2	1.2	10.7	15.2	4.3	0.4	0.4	0.2
Winter	20-40%	0203	2.0	3.5	6.5	0.0	0.0	0.0	5.9	7.2	2.3	2.6	0.6	0.0
		0305	0.4	0.9	7.0	0.1	2.4	5.8	5.3	16.1	10.6	1.6	0.6	0.3
		0306	0.1	0.6	9.6	0.3	1.4	4.6	7.6	17.5	9.6	0.6	0.3	0.0
		0307	0.0	2.8	6.6	0.0	0.1	0.8	5.5	17.5	8.7	1.9	0.6	0.1
		0501	0.4	1.5	5.3	0.0	0.8	7.2	5.5	15.5	2.1	1.5	0.7	0.1
		0502	0.0	0.4	0.6	0.0	1.1	2.5	3.1	17.4	9.5	0.3	0.0	0.0
		0504	0.3	2.0	7.8	0.5	1.7	2.7	7.7	18.0	3.2	1.3	0.4	0.2
Winter	40%+	0104	0.4	1.0	5.2	0.0	0.0	0.0	7.3	10.5	5.1	2.8	0.4	0.4
		0105	0.9	1.5	8.9	0.0	0.0	0.0	9.2	15.4	9.3	5.3	0.0	0.2
		0402	0.5	0.3	9.5	0.0	0.0	4.5	3.5	15.9	18.5	0.3	0.0	0.0

Table III-4. Soil disturbance data (degrees) for ANOVA test #2: Summer and winter groundskidding on slopes <20%, 20-40%, and >40%.

			SOIL DISTURBANCE ASSOCIATED WITH											
			HAUL ROADS			LANDINGS			SKID ROADS			YARDING		
LOGGING SEASON	SLOPE CLASS	BLOCK NUMBER	LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP	LIGHT	DEEP	VERY DEEP
Summer	0-20%	0302	0.0	4.8	0.0	3.1	6.3	0.0	23.2	16.1	5.1	10.5	3.6	0.0
		0304	2.6	8.9	17.9	4.4	14.4	13.1	15.0	26.9	19.3	6.8	4.1	0.0
		0403	3.1	5.9	12.9	4.8	9.8	8.9	14.5	12.5	7.9	11.1	7.3	3.1
		0503	0.0	7.3	16.3	6.5	10.5	21.5	15.2	28.2	15.6	5.4	2.6	0.0
Summer	20-40%	0101	7.9	8.9	16.2	0.0	0.0	7.0	12.8	12.2	7.3	10.6	5.1	0.0
		0303	3.6	4.1	10.0	1.8	5.4	10.5	16.4	21.6	18.8	8.9	4.1	4.1
		0506	1.8	6.0	18.0	1.8	5.1	11.5	15.0	25.7	16.2	5.1	4.1	0.0
Summer	40%+	0201	4.1	6.0	15.0	0.0	0.0	3.1	14.1	18.0	20.0	7.0	1.8	0.0
		0308	3.1	5.4	12.1	0.0	0.0	1.8	10.9	19.7	28.2	10.0	5.1	4.4
		0507	6.0	7.3	22.5	0.0	0.0	9.1	12.8	21.4	25.0	8.9	7.0	5.7
Winter	0-20%	0202	8.1	14.2	10.3	1.8	5.1	3.1	21.6	17.0	12.8	14.7	10.9	4.8
		0401	4.4	13.1	8.9	2.6	15.5	11.2	16.5	7.9	5.4	21.6	3.1	0.0
		0405	5.1	6.5	4.8	11.1	10.9	7.9	8.7	9.8	6.0	13.8	6.5	3.1
		0406	5.1	8.3	6.0	7.9	7.3	0.0	7.5	3.6	2.6	10.8	3.1	1.8
		0505	1.8	3.6	6.8	0.9	8.5	6.3	19.1	22.9	12.0	3.6	3.6	2.6
Winter	20-40%	0203	8.5	10.5	14.8	0.0	0.0	0.0	14.1	15.6	8.7	9.3	4.4	0.0
		0305	3.6	5.4	15.3	1.8	8.9	13.9	13.3	23.7	19.0	7.3	4.4	3.1
		0306	1.8	4.4	18.0	3.1	6.8	12.4	16.0	24.7	18.0	4.4	3.1	0.0
		0307	0.0	9.6	14.9	0.0	1.8	5.1	13.6	24.7	17.2	7.9	4.4	1.8
		0501	3.6	7.0	13.3	0.0	5.1	15.6	13.6	23.2	8.3	7.0	4.8	1.8
		0502	0.0	3.6	4.4	0.0	6.0	9.1	10.1	24.7	18.0	3.1	0.0	0.0
		0504	3.1	8.1	16.2	4.1	7.5	9.5	16.1	25.1	10.3	6.5	3.6	2.6
Winter	40%+	0104	3.6	5.7	13.2	0.0	0.0	0.0	15.7	18.9	13.1	9.6	3.6	3.6
		0105	5.4	7.0	17.4	0.0	0.0	0.0	17.7	23.1	17.8	13.3	0.0	2.6
		0402	4.1	3.1	18.0	0.0	0.0	12.2	10.8	23.5	25.5	3.1	0.0	0.0

APPENDIX IV

SOIL DISTURBANCE SURVEYS:

SUMMARY OF STATISTICAL ANALYSES.

INTRODUCTION

Data from the soil disturbance surveys was analyzed by Analysis of Variance (ANOVA) techniques. The basic unit of analysis was percent disturbance per depth class, transformed to degree data via an arcsine $\sqrt{\text{percentage}}$ transformation to normalize the information. The analyses involved fourfold classifications of the disturbance data and employed randomized block designs with uneven subgroup sizes.

Two analyses were performed. The first compared disturbance data for cable-yarded clearcuts and groundskidded clearcuts having average slopes of 20% or more. The second stratified and compared all groundskidded clearcuts by season of logging and by slope classes of less than 20%, 20% to 40%, and more than 40%.

Tables of raw and transformed data used in these analyses are presented in Appendix II.

Means of all highly significant main effects and interactions were compared using Newman-Kuels Range Test methods.

ANOVA tables for the two analyses (presented as Table 2 and 3 in Section 4, Results) are reproduced here. Following each ANOVA table are tables summarizing each Newman-Kuels Range Test that was performed on the ANOVA results.

Table IV-1. Analysis of Variance - cable yarding versus groundskidding on slopes >20%.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F	$F_{0.05}$	$F_{0.01}$	SIGNIFICANCE[1]
1. Main Effects							
Method of Logging (M)	1	380.45	380.45	32.91	3.84	6.63	**
Season of Logging (Se)	1	5.88	5.88	0.51	3.84	6.63	N.S.
Source of Disturbance (Sd)	3	4,351.65	1,450.55	125.48	2.60	3.78	**
Depth of Disturbance (De)	2	346.45	173.23	14.99	3.00	4.61	**
2. Interactions							
Method x Season (M x Se)	1	38.16	38.16	3.30	3.84	6.63	N.S.
Method x Source (M x Sd)	3	2,202.76	734.25	63.52	2.60	3.78	**
Method x Depth (M x De)	2	132.48	66.24	5.73	3.00	4.61	**
Season x Source (Se x Sd)	3	175.46	58.49	5.06	2.60	3.78	**
Season x Depth (Se x De)	2	28.35	14.18	1.23	3.00	4.61	N.S.
Source x Depth (Sd x De)	6	2,773.26	462.21	39.98	2.10	2.80	**
M x Se x Sd	3	68.00	22.67	1.96	2.60	3.78	N.S.
M x Se x De	2	26.93	13.47	1.17	3.00	4.61	N.S.
M x Sd x De	6	138.64	23.11	2.00	2.10	2.80	N.S.
Se x Sd x De	6	130.88	21.81	1.89	2.10	2.80	N.S.
M x Se x Sd x De	6	58.87	9.81	0.85	2.10	2.80	N.S.
3. Error	216	2,497.00	11.56				
4. Total	263						

[1]Levels of Significance: ** - Significant at 99% level.
* - Significant at 95% level.
N.S. - Not Significant at 95% level.

Table IV-1a. Results of Newman-Kuels Range Test -- cable versus groundskidding on slopes >20%.
a. source of disturbance

SOURCE OF DISTURBANCE[1]	MEAN DISTURBANCE[2]		SIGNIFICANCE LEVELS[3]	
	DEGREES	PERCENT	5%	1%
Skid Roads	13.82	5.7	a	a
Haul Roads	8.82	3.4	b	b
Yarding	5.03	0.87	c	c
Landings	3.19	0.31	d	c

Table IV-1b. Results of Newman-Kuels Range Test -- cable versus groundskidding on slopes >20%.
b. depth of disturbance

DEPTH OF DISTURBANCE	MEAN DISTURBANCE		SIGNIFICANCE LEVELS	
	DEGREES	PERCENT	5%	1%
Very Deep	9.20	2.6	a	a
Deep	7.58	1.7	b	b
Light	6.40	1.2	c	b

[1]Sources are listed in order of decreasing rank.
[2]The means given (degree and percentage) are those calculated from the ANOVA (Table IV-1). Newman-Kuels Range Test is applied to transformed (arcsine $\sqrt{\text{percentage}}$) data, not percentage information. The statistical results, however, are also valid for he original percentage data.
[3]Means followed by the same letter are not significantly different at the stated level of confidence.

Table IV-1c. Results of Newman-Kuels Range Test -- cable versus groundskidding on slopes >20%. c. method of logging X source of disturbance

MEANS BEING COMPARED (METHOD/SOURCE)	MEAN DISTURBANCE DEGREES	MEAN DISTURBANCE PERCENT	SIGNIFICANCE LEVELS 5%	SIGNIFICANCE LEVELS 1%
Groundskidding, Skid roads	17.50	9.0	a	a
Cable yarding, Haul roads	10.29	3.2	b	b
Groundskidding, Haul roads	8.29	2.1	bc	bc
Cable yarding, Yarding	6.97	1.5	c	cd
Groundskidding, Yarding	4.31	0.6	d	d
Cable yarding, Skid roads	4.00	0.5	de	de
Groundskidding, Landings	3.75	0.4	de	de
Cable yarding, Landings	1.79	0.1	e	e

Table IV-1d. Results of Newman-Kuels Range Test -- cable versus groundskidding on slopes >20%. d. method of logging X depth of disturbance

MEANS BEING COMPARED (METHOD/DEPTH)	MEAN DISTURBANCE DEGREES	MEAN DISTURBANCE PERCENT	SIGNIFICANCE LEVELS 5%	SIGNIFICANCE LEVELS 1%
Groundskidding/Very deep	10.26	3.2	a	a
Groundskidding/Deep	8.59	2.2	b	b
Groundskidding/Light	6.52	1.3	c	c
Cable/Very deep	6.35	1.2	cd	c
Cable/Light	6.08	1.1	cd	c
Cable/Deep	4.86	0.7	d	c

Table IV-1e. Results of Newman-Kuels Range Test -- cable versus groundskidding on slopes >20%.
e. season of logging X source of disturbance

MEANS BEING COMPARED (SEASON/SOURCE)	MEAN DISTURBANCE DEGREE	PERCENT	SIGNIFICANCE LEVELS 5%	1%
Winter, Skid roads	14.31	6.1	a	a
Summer, Skid roads	13.12	5.2	a	a
Winter, Haul roads	8.94	2.4	b	b
Summer, Haul roads	8.66	2.3	b	b
Summer, Yarding	6.87	1.4	c	b
Winter, Yarding	3.76	0.4	c	c
Winter, Landings	3.39	0.3	d	c
Summer, Landings	2.96	0.3	d	c

Table IV-1f. Results of Newman-Kuels Range Test -- cable versus groundskidding on slopes >20%.
f. source of disturbance X depth of disturbance

MEANS BEING COMPARED (SOURCE/DEPTH)	MEAN DISTURBANCE DEGREES	PERCENT	SIGNIFICANCE LEVELS 5%	1%
Skid roads, Deep	17.25	8.8	a	a
Haul roads, Very deep	15.56	7.2	a	ab
Skid roads, Very deep	13.39	5.4	b	bc
Skid roads, Light	10.81	3.5	c	cd
Yarding, Light	9.58	2.8	c	d
Haul roads, Deep	6.58	1.3	d	e
Landings, Very deep	6.34	1.2	d	e
Haul roads, Light	4.33	0.6	de	ef
Yarding, Deep	4.04	0.5	de	efg
Landings, Deep	2.42	0.2	ef	fg
Yarding, Very deep	1.49	0.1	f	fg
Landings, Light	0.89	<0.1	f	g

Table IV-2. Analysis of Variance - summer versus winter groundskidding on slopes <20%, 20% to 40%, and >40%.

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F	$F_{0.05}$	$F_{0.01}$	SIGNIFICANCE[1]
1. Main Effects							
Season of Logging (M)	1	18.99	18.99	1.23	3.84	6.63	N.S.
Slope Class (Se)	2	1.18	0.59	0.04	3.00	4.61	N.S.
Source of Disturbance (Sd)	3	6,309.03	2,103.01	136.29	2.60	3.78	**
Depth of Disturbance (De)	2	211.03	105.52	6.84	3.00	4.61	**
2. Interactions							
Season x Slope (Se x Sl)	2	14.43	7.22	0.47	3.00	4.61	N.S.
Season x Source (Se x Sd)	3	35.31	11.77	0.76	2.60	3.78	N.S.
Season x Depth (Se x De)	2	40.95	20.48	1.33	3.00	4.61	N.S.
Slope x Source (Sl x Sd)	6	752.24	125.37	8.13	2.10	2.80	**
Slope x Depth (Sl x De)	4	438.72	109.68	7.11	2.37	3.32	**
Source x Depth (Sd x De)	6	2,330.48	388.41	25.17	2.10	2.80	**
Se x Sl x Sd	6	194.02	32.34	2.10	2.10	2.80	N.S.
Se x Sl x De	4	82.54	20.64	1.34	2.37	3.32	N.S.
Se x Sd x De	6	24.73	4.12	0.27	2.10	2.80	N.S.
Sl x Sd x De	12	362.34	30.20	1.96	1.75	2.18	*
Se x Sl x Sd x De	12	131.81	10.98	0.71	1.75	2.18	N.S.
3. Error	228	3,518.98	15.43				
4. Total	299						

[1]Levels of Significance:
** - Significant at 99% level.
* - Significant at 95% level.
N.S. - Not significant at 95% level.

Table IV-2a. Results of Newman-Kuels Range Test -- summer versus winter groundskidding on slopes <20%, 20% to 40%, and >40%. a. source of disturbance

MEANS BEING COMPARED	MEAN DISTURBANCE		SIGNIFICANCE LEVELS	
(SOURCE)	DEGREES	PERCENT	5%	1%
Skid roads	16.17	7.8	a	a
Haul roads	7.77	1.8	b	b
Landings	5.10	0.8	c	c
Yarding	4.88	0.7	c	c

Table IV-2b. Results of Newman-Kuels Test -- summer versus winter groundskidding on slopes <20%, 20% to 40%, and >40%. b. depth of disturbance

MEANS BEING COMPARED	MEAN DISTURBANCE		SIGNIFICANCE LEVEL	
(DEPTH CLASS)	DEGREES	PERCENT	5%	1%
Very deep	9.15	2.5	a	a
Deep	9.00	2.4	a	a
Light	7.30	1.6	b	b

Table IV-2c. Results of Newman-Kuels Range Test -- summer versus winter groundskidding on slopes of <20%, 20% to 40%, and >40%. c. slope X source of disturbance

MEANS BEING COMPARED	MEAN DISTURBANCE		SIGNIFICANCE LEVELS	
(SOURCE/SLOPE CLASS)	DEGREES	PERCENT	5%	1%
Skid roads, 40%+	18.68	10.3	a	a
Skid roads, 20% to 40%	16.80	8.4	a	a
Skid roads, <20%	13.81	5.7	b	b
Haul roads, 40%+	8.58	2.2	c	c
Haul roads, 20% to 40%	8.09	2.0	c	c
Landings, <20%	7.50	1.7	c	c
Haul roads, <20%	6.89	1.4	cd	c
Yarding, <20%	5.87	1.0	cd	c
Landings, 20% to 40%	5.13	0.8	cd	c
Yarding, 40%+	4.76	0.7	cd	cd
Yarding, 20% to 40%	4.05	0.5	d	cd
Landings, 40%+	1.46	0.1	e	d

Table IV-2d. Results of Newman-Kuels Range Test -- summer versus winter groundskidding on slopes <20%, 20% to 40%, and >40%. d. slope X depth of disturbance

MEANS BEING COMPARED	MEAN DISTURBANCE		SIGNIFICANCE LEVELS	
(DEPTH/SLOPE CLASS)	DEGREES	PERCENT	5%	1%
Very deep, 40%+	11.08	3.7	a	a
Very deep, 20% to 40%	9.77	2.9	a	a
Deep, <20%	9.72	2.8	ab	ab
Deep, 20% to 40%	9.34	2.6	abc	abc
Light, <20%	8.67	2.3	abcd	abc
Deep, 40%+	7.36	1.6	bcd	abc
Very deep, <20%	7.17	1.6	cd	abc
Light, 40%+	6.68	1.4	d	bc
Light, 20% to 40%	6.44	1.3	d	c

Table IV-2e. Results of Newman-Kuels Range Test -- summer and winter groundskidding on slopes <20%, 20% to 40%, and >40%.
e. source of disturbance X depth of disturbance

MEANS BEING COMPARED (SOURCE/DEPTH)	MEAN DISTURBANCE		SIGNIFICANCE LEVELS	
	DEGREES	PERCENT	5%	1%
Skid roads, Deep	19.63	11.3	a	a
Skid roads, Light	14.57	6.3	b	b
Skid roads, Very deep	14.32	6.1	b	b
Haul roads, Very deep	12.75	4.9	b	b
Yarding, Light	8.81	2.3	c	c
Landings, Very deep	7.71	1.8	cd	c
Haul roads, Deep	6.96	1.5	cd	cd
Landings, Deep	5.40	0.9	de	cde
Yarding, Deep	4.01	0.5	ef	de
Haul roads, Light	3.62	0.4	ef	de
Landings, Light	2.19	0.1	f	e
Yarding, Very deep	1.80	0.1	f	e

APPENDIX V

SUMMARIES OF ANALYSES AND COMPARISONS OF SOIL PROPERTIES ON SKID ROAD SURFACES.

INTRODUCTION

Values for five soil properties (pH, carbon content, bulk density, particle-size distributions, and fifteen-minute infiltration rates) were determined along a transect extending from the undisturbed soil surface immediately above a cut bank of a skid road, across the skid road surface, to the base of the fill slope on the downslope side. Five such determinations were made, each on a separate skid road, on each of the Quartz Creek and Rock Creek study sites.

Statistical differences were established by examining each soil property individually by Analysis of Variance (ANOVA) techniques. Where ANOVA indicated statistically significant differences existed, the Newman-Kuels Range Test or Student's t-test was applied depending upon the comparisons of interest and the numbers of means to be tested. The Newman-Kuels Range Test was applied to examine within-block differences involving more than two means (i.e. to examine variations within the skid road cross-section of a given study site). The Student's t-test was used to test means between the two study sites.

Tables of ANOVA and pertinent means tests follow.

V-1: Soil pH

Table V-1. Analysis of Variance - soil pH versus location in a skid road cross-section.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F	$F_{0.05}$	$F_{0.01}$	SIGNIFICANCE[1]
1. MAIN EFFECTS							
Block (Tr)	1	37.52	37.52	73.54	4.26	7.82	**
Cross-section location (Cs)	2	12.52	6.26	12.27	3.40	5.61	**
2. INTERACTION							
Tr X Cs	2	0.29	0.15	0.29	3.40	5.61	N.S.
3. ERROR	24	12.25	0.51				
TOTAL	29						

[1]Levels of significance: ** - significant at 99% level.
* - significant at 95% level.
N.S. - not significant at 95% level.

Table V-1a. Results of Newman-Kuels Range Test - soil pH versus location in a skid road cross-section.

MEANS BEING COMPARED	MEAN pH	SIGNIFICANCE LEVELS 5%	1%
a. Quartz Creek			
Undisturbed surface soil	4.46	a	a
Base of cutbank (C-horizon)	5.69	b	a
Skid road surface	5.54	b	a
b. Rock Creek			
Undisturbed surface soil	6.43	a	a
Base of cutbank (C-horizon)	8.13	b	b
Skid road surface	7.84	b	b

V-2: Soil Carbon Content

Table V-2. Analysis of Variance - organic carbon, calcium carbonate and total carbon contents versus location in a skid road cross-section.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F	$F_{0.05}$	$F_{0.01}$	SIGNIFICANCE
1. MAIN EFFECTS							
Block (Tr)	1	191.20	191.20	6.77	4.00	7.08	*
Cross-section location (Cs)[1]	2	103.81	51.91	1.84	3.15	4.98	N.S.
Soil Parameter (Sp)[2]	2	266.06	133.03	4.71	3.15	4.98	*
2. INTERACTIONS							
Tr X Cs	2	154.81	77.41	2.74	3.15	4.98	N.S.
Tr X Sp	2	457.04	228.52	8.09	3.15	4.98	**
Cs X Sp	4	222.07	55.52	1.96	2.53	3.65	N.S.
Tr X Cs X Sp	4	176.47	44.12	1.56	2.53	3.65	N.S.
3. ERROR	72	2,034.54	28.26				
TOTAL	89						

[1]Samples were taken from the undisturbed soil surface, base of cutbank and skid road surface.
[2]Soil parameters are organic carbon, calcium carbonate, and total carbon contents.

Table V-2a. Results of Student's t-Test - comparisons of organic carbon, calcium carbonate, and total carbon contents between Quartz Creek and Rock Creek study sites.

MEANS BEING COMPARED	MEANS FOR		t	$t_{0.05}$	$t_{0.01}$	SIGNIFICANCE
	QUARTZ CREEK	ROCK CREEK				
Organic carbon	1.14%	0.33%	3.526	2.145	2.977	**
Calcium carbonate	0.00	9.26	3.755	2.145	2.977	**
Total carbon	1.14	1.44	0.883	2.145	2.977	N.S.

V-3: Soil Bulk Density

Table V-3. Analysis of Variance - soil bulk density versus location in a skid road cross-section.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F	$F_{0.05}$	$F_{0.01}$	SIGNIFICANCE
1. MAIN EFFECTS							
Block (Tr)	1	0.99	0.99	10.30	4.08	7.31	**
Cross-section location (Cs)	5	2.15	0.43	4.47	2.45	3.51	**
2. INTERACTION							
Tr X Cs	5	0.14	0.03	0.28	2.45	3.51	N.S.
3. ERROR	48	4.62	0.096				
TOTAL	59						

Table V-3a. Results of Newman-Kuels Range Test - soil bulk density versus location in a skid road cross-section for Quartz Creek and Rock Creek.

MEANS BEING COMPARED[1]	QUARTZ CREEK		ROCK CREEK	
	MEAN	SIGNIFICANCE[2]	MEAN	SIGNIFICANCE[2]
Base of cutbank	1.57 g/cm^3	a	1.67 g/cm^3	a
Inner track	1.26	ab	1.61	ab
Center track	1.17	ab	1.54	ab
Outer track	1.15	ab	1.42	ab
Undisturbed surface	1.09	b	1.35	ab
Sidecast	0.91	b	1.10	b

[1]See Figure 4, p. 48, for definitions of skid road zones.
[2]Significance at 99% level.

V-4: Soil Texture (Particle-Size Distribution)

Analysis of Variance showed no significant differences in soil textures (sand, silt and clay components) or in the minus -2 mm soil fraction between undisturbed surface soils and skid road surfaces.

V-5: Fifteen-Minute Infiltration Rates

Table V-5. Analysis of Variance - fifteen-minute infiltration rates for undisturbed soils and skid road surfaces, Quartz Creek and Rock Creek.

SOURCE OF VARIATION	D.F.	S.S.	M.S.	F	$F_{0.05}$	$F_{0.01}$	SIGNIFICANCE
1. MAIN EFFECTS							
Block (Tr)	1	483.20	483.20	2.59	4.49	8.53	N.S.
Cross-section location (Cs)	1	976.66	976.66	5.24	4.49	8.53	*
2. INTERACTION							
Tr X Cs	1	104.74	104.74	0.56	4.49	8.53	N.S.
3. ERROR	16	2,984.31	186.52				
TOTAL	19						

APPENDIX VI

DESCRIPTIONS OF CABLE LOGGING SYSTEMS.

INTRODUCTION

This appendix contains brief descriptions of cable yarding systems that have been or are now being used in the Nelson Forest Region. The list of cable systems is by no means complete. Descriptions of the yarding systems and their capabilities have been abstracted from Burke (1972), Cottell, McMorland and Wellburn (1976), Larsen (1978), Mann (1977), Studier and Binkley (1974), and Wellburn (1974, 1975). Readers requiring more information about cable yarding systems are urged to consult these references for detailed descriptions and illustrations. Mifflin and Lysons (1979)[1] is also a useful reference for cable yarding terminology and definitions.

Cable yarding systems most commonly used in the past or currently in the Nelson Forest Region include jammer, high-lead and running skyline (with grapple or chokers) systems. Operators have also experimented with live skyline and standing skyline systems.

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[1]Mifflin, R.W., and H.H. Lysons. 1979. Glossary of Forest Engineering Terms. USDA For. Serv., Pacific Northwest For. and Range Exp. Sta., Portland, Ore. 24 pp.

1. Jammer

The jammer system is a short-distance cable yarding system that was used extensively 20 to 30 years ago but receives less use today. In its most common form it consisted of a two-drum yarder (mainline and haulback line) and a short wood or steel tower and was mounted on a truck frame or tractor undercarriage. The tower was supported by 2 or 3 guylines. The haulback line passed through haulback blocks at the tailholds and was connected to the mainline via a squirrel block or other form of butt rigging. The haulback drum normally could not be braked during inhaul, so as a result the front of a turn could not be lifted clear of the ground. This, coupled with the short tower, limited jammer logging to relatively short yarding distances of approximately 400 feet uphill and 200 feet downhill.

2. Highlead

Highlead systems are similar to jammer systems in that they also have two drums, one each for the main and haulback lines. However, the haulback drum can be braked to partially suspend the turn during inhaul.

Most highlead yarders are mounted on self-propelled tracked or rubber-tired undercarriages and have a steel tower ranging from 30 to 120 feet in height (the taller towers are telescoping). The tower is raised and lowered, and supported when in the upright position, by six guylines. As with the jammer system, the haulback is passed through a series of haulback blocks rigged to tailhold stumps or backspars, and is secured to the mainline via an assembly of swivels and shackles collectively referred to as butt rigging. Chokers are also connected to the butt rigging with line swivels and butt hooks.

During inhaul the haulback drum can be braked, tightening the lines and thereby lifting the front end of the turn clear of the ground (providing there is adequate deflection). The term "highlead" is derived from this feature. Yarding distances are longer as a result of the better lead, more powerful yarders and taller towers: average yarding distances of 600 to 800 feet uphill and 400 to 600 feet downhill are common, and longer yarding distances are possible if deflection is favourable.

3. Running Skyline

The term "running skyline" is used to describe a variety of cable yarding systems which couple the haulback line and mainline to provide increased lift to the turn. A carriage or a block, depending upon the particular system being used, runs on the haulback line and also connects the haulback and mainlines. The haulback line from the yarder passes through the sheaves of the carriage (or a single block), through a haulback block at the tailhold, and returns to the back of the carriage (or back end of the butt rigging). The main-line from the yarder is connected directly to the front of the carriage or butt rigging. Both lines have braking capacity to control line tensions. Lift is provided to the turn by maintaining sufficient tension in the lines to keep the carriage or block suspended above the ground during inhaul or outhaul.

The yarder may be a two- or three-drum machine. With a two-drum yarder a "two-line running skyline" known as a "scab-line" or "Grabinsky" system is commonly used. In this system the haulback and mainlines are connected via the butt rigging as in the normal highlead fashion. A block (usually a haulback block), attached to the segment of haulback line

between the tower and the tailhold, is also connected to the butt rigging as well. Consequently when one line is braked and the other tightened, a vertical lifting force is applied as the haulback line lifts up during tightening. Standard highlead yarders using chokers can operate as two-line running skyline systems.

Three-drum yarders are in general specially designed to operate as skyline systems. Machines designed for running skyline systems usually consist of a leaning steel lattice "crane" (hence may be called "yarding cranes") or tower 40 to 60 feet high. The tower is supported by lines to a gantry, which in turn is secured by guylines when the tower is in the raised position. Many of these yarders are mounted on turntables to allow them to "swing" and deck the turn beside rather than in front of the machine.

The three drums carry the haulback, main and slackpulling lines. The haulback line is rigged through the carriage sheaves, around the haulback block at the tailhold and then to the rear of the carriage. The mainline passes around a sheave at the front of the carriage and is connected to the slackpulling line; hence the mainline and slackpulling line

work in opposition. A dropline is connected to the mainline and passes through the bottom of the carriage. It is raised or lowered by adjusting the motions of the main and slack-pulling lines.

Grapple yarders are running skyline systems and work according to the above principles. In the case of grapple yarders, however, the dropline serves to open and close the grapple. When chokers are used its function is to lower the chokers to the rigging crew or to allow the lines to be pulled laterally across the yarding road.

Yarding distances for running skyline systems vary considerably. For systems such as grapple yarding, which is normally capable of handling only one log per turn and has very limited lateral yarding capability, short distance (400 to 600 feet) are preferred. When chokers are used and lateral yarding is possible yarding distances of 1,000 to 1,200 feet may be practical.

4. Live and Standing Skylines

Unlike running skyline systems, in which the haulback line also acts as the skyline, live and standing skylines are stationary during inhaul and outhaul. In running skyline systems line tensions must be carefully controlled to keep the turn fully or partially suspended (this may be done automatically, with an interlocking mechanism to control drum speeds, or manually). In live and standing skyline systems, because the skyline is fixed, skyline tension does not need to be adjusted during inhaul or outhaul.

Live skylines differ from standing skylines in that the skyline is mounted on one drum of the yarder and is used to lower the carriage and chokers to the rigging crew. Standing skylines may be mounted on the yarder or controlled from a separate, independent winch, but once positioned and tensioned are not routinely slacked and tightened except to change yarding roads.

Yarders for live skyline systems must be three- or four-drum machines (although gravity skyline systems can be used with two-drum yarders). A four-drum yarder has a skyline, mainline, slackpulling line and haulback line, while a three-

drum yarder lacks the slackpulling line. Yarders are mobile, mounted on tracked or rubber-tired undercarriages, and range from 40 to 120 feet tall. Seven to eight guylines are required for large yarders.

Gravity skyline systems can be used with standard two-drum yarders. For these systems the mainline serves as the skyline and the haulback in effect becomes the mainline, and is used to pull turns into the landing. The carriage and rigging is returned to the woods by releasing the haulback brake and letting gravity pull the carriage down the skyline. The system is therefore limited to uphill yarding only on steep slopes (at least 30%).

Standing skyline systems can be used with two-drum yarders if the skyline is mounted on a separate winch, or with three- or four-drum yarders if it is stored on the yarder.

These systems have the longest average yarding distances of any cable yarding systems with maximums of 2,000 to 5,000 feet depending upon which configuration is used. They are most efficient in the 1,000- to 1,500-foot range. Below this distance highlead and running skyline systems are more effective because of their less complex rigging requirements.

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